Sustainable Mobile Architecture for Natural Disasters with Reference to the Experience of the Bam Earthquake

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Abstract

During the Bam Earthquake (Iran, 2003) and Sichuan Earthquake (China, 2008) the emergency services learnt how important is their speed in providing sustainable emergency shelters and first aid points for survivors. They understood that they must have different strategies for planning in different locations (Yayong, 2008; Zhai, 2008). All governments and NGOs, such as the Red Cross and Red Crescent Society respond to natural disasters by organizing emergency services for earthquakes, floods and storms. They provide well-organized systems and quick for immediate architectural needs such as field hospitals for temporary care and rehabilitation of the survivors in disaster areas where shelters are rapidly located and erected (Babister and Kelman, 2002; de Magaz et al., 2005). In emergency cases, temporary structures are vitally important to save human life. Also speed in making decisions and saving energy in such situations is very important (Hinde, 1974). Architectural development in the future should address the issues relating to this type of sustainable, environmental and natural degradation, but must also be economically responsive. Also the architectural development should meet special needs specifically identified by NGOs and disaster relief charities.

The United Nations has provided a manifesto for unique disaster response cycles and a strategy for disaster reduction for emergency services, which consist of different stages such as sheltering, landscape recovery and urban recovery (Griekspoor and Collins, 2001). There is a process for sheltering in a Disaster Response Cycle (Babister and Kelman, 2002) that needs to be updated because of the increasing the world's population (Bolin, 1994) and the increasing number of natural disasters through time (Chart 1.1). In response to this situation the research discussed here looking at sustainable emergency shelters (Comerio, 1997 and US-Census, 2004; Ban, 2006) in the form of the application of deployable structures (Pellegrino, 2001 and Guest, 2000; Gantes and Konitopoulou, 2004), and at key designers such as Buckminster Fuller (Gorman, 2005). Examples from around the world such as those developed at the DSL workshop in the Cambridge School of Architecture and Lincoln Lab in the MIT Department of Engineering are explored; these structures are then categorized by shape and erection mechanism so that they may be examined by type. In addition, their suitability in different situations or locations and their advantages and disadvantages are examined.

The contribution of this research to knowledge is the innovative application of deployable architectural technologies to long-term disaster relief. An important part of the process is to develop a deployable architecture, providing self-construction emergency shelters based on low-tech traditional skills such as origami (Slatin, 2003) and familiar materials such as cardboard, paper and plastics products in a post-earthquake scenario and how the structural mechanism such as erection and folding can be predicted for different conditions. Furthermore, the sustainability of existing equipment for emergency sheltering, advantages and disadvantages are evaluated.

In terms of sustainability in emergency sheltering, the following areas are explored in separate chapters to identify the efficient options: material (Maeda and Suzuki, 2011; Ritter, 2007) method (Fellows and Liu, 2009; Jodidio, 2011), deployment (De Temmerman, 2007) and energy (Mansfield, 2000; Marsh, 2003).

Acknowledgment:

Foremost, I would like to express my deepest thanks to my supervisors, Professor Tom Jefferies and Eamonn Canniffe. Their patience, encouragement, and immense knowledge were key motivations throughout my PhD. They have guided me through every stage of this research and contributed many ideas to its development. Their unwavering support is greatly appreciated and their guidance has proved invaluable.

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Glossary of acronyms

NGO	Non- Govermental Organization
RIBA	Royal Institute of British Architects
UN	United Nations
MIT	Massachusetts Institute of Technology
MMU	Manchester Metropolitan University
DSL	Deployable Structure Laboratory
UNHCR	United Nations High Commissioner for Refugees
UNDRO	United Nations Disaster Relief Organization
UNESCO	United Nations Educational, Scientific and Cultural Organization
NASA	National Aeronautics and Space Administration
MRS	Materials Research Society
WHC	World Heritages Centre
WHS	World Heritages Site
NGO	Non-Governmental Organization
OCHA	Office for the Coordination of Humanitarian Affairs

Introduction to the thesis

Generally, temporary sheltering is one of the stages of earthquake response cycle when emergency NGOs and earthquake survivors are struggling in post-earthquake scenarios. Many resources would be wasted for this stage including emergency sheltering and transitional sheltering. In the Bam earthquake in 2003 this issue occurred because of inefficient management and gaps in providing temporary shelters which caused many psychological, cultural and social problems.

The experience of Bam earthquake was one of important experiences in the international scale of responding and reconstruction in Iran that had many lessons for national and international emergency NGOs. The author's experience in Bam earthquake and interviews with engaged people in Bam earthquake affected different parts of this research.

This research is the result of personal experience, fieldwork, using library resources and data collection for identification of gaps in providing immediate architectural needs in post-earthquake scenarios. In addition, observation of existing situations, interviews with experts and local people in Bam helped to develop different parts of this research in different aspect. The structure of this thesis consists of six chapters as below.

As Chapter One Literature Review, mostly provides information about the humanitarian sector and its models of operation referencing to Bam earthquake post-earthquake scenarios and to the problems surrounding temporary sheltering and reconstruction. This chapter includes basic information in different areas to provide an efficient reference for future studies about temporary sheltering. This chapter starts with sustainable development, advantages and disadvantages of existing situations in temporary sheltering. It includes existing developments related to existing problems. In addition, reasons/ sources/ scales and approaches of earthquakes are considered in the Literature Review. Process of temporary sheltering in post-earthquake scenarios, lessons from previous experiences specifically Bam earthquake are provided. The Bam earthquake section includes general information about Bam earthquake and earthquake response cycle during operation. Finally, Literature Review supports Chapters Five and Six providing information about structural design and material design for emergency sheltering.

Chapter Two as Research Methodology is divided in two parts. Firstly, there are theoretical parts of the research methodology. This part introduces different references related to temporary sheltering and extracts research methods to give an efficient structure to different areas of this research. Different references and their research methods are considered to design questionnaire forms. Those questionnaire forms identified gaps during Bam emergency sheltering. The second part considers practical research methods to translate developed virtual models to physical models. The output of those practical research methods appears in Volume 2 as portfolio.

Chapter Three as Field Work provides information about situations before and after Bam earthquake and strategies which national and international NGOs selected. At the beginning, general information about Bam are introduced then accurate fieldwork related to 2 types of temporary sheltering are expanded to identify the gaps in temporary sheltering during the Bam earthquake. Questionnaire forms which were designed in chapter 2, provide different statistics and tables in this chapter. This chapter outlines those areas of temporary sheltering which require development.

Chapter Four as Disaster Response Cycle focuses to answer the first research question to identify immediate architectural needs of survivors in post-earthquake scenario through discussing the daily basis of activities from few hours after the earthquake until 6 months later. Different strategies of NGOs were discussed to identify their activities, required spaces for those activities and immediate needs of survivors. This chapter discusses environmental issues in emergency sheltering and sustainable methods to develop emergency sheltering.

Chapters Five and Six are designed to respond to the second research question. Chapter Five as Structural Design discusses the development of sustainable temporary structures which are identified in the Literature Review. Those selected options are discussed to support immediate or longer term needs of earthquake survivors. It starts discussing about natural geometry and mathematics in structural design and research implications in structural design process for emergency sheltering. This chapter focuses on deployable structures through architectural and engineering focus to simplify erection mechanism to maximise public engagement.

Chapter Six as Material Design Chapter plays an important role in the efficiency of prototypes. This chapter focuses on lightweight material options and discusses a material selection approach for this research. In the next step, it categorizes primary and secondary material options for more sustainability. Different sustainable methods of material selection are proposed in this chapter and those are applied during prototyping. Different factors for material selection from industries such as availability, sustainability are discussed in this chapter.

Finally, this research through discussions and implications in different chapters, proposed different prototypes. These proposed prototypes are translated from virtual models to physical models to be tested and evaluate its efficiency. The process of this translation starts from virtual models, small scale modelling and actual scale. Different stages of prototyping, workshops, and evaluations are presented in Volume B of this research.

This research with consideration of the existing problems in temporary sheltering during earthquakes in Iran and international emergency NGOs experience during earthquake response cycle outlines 2 research questions.

Research questions:

In 1985, The United Nations Disaster Relief Organization manifesto (Gostelow, 1999: 261) declared:

"A number of developments in the humanitarian sector and other relevant areas have arisen over the past few years, encompassing changes in the nature of disasters and conflicts, as well as of humanitarian work. (Section humanitarian sector p.10) Defined shelter solutions such as family tents, shelter kits, packages of materials or prefabricated buildings should be provided where local post-disaster shelter options are not readily available, are inadequate or cannot be sustainably supported by the local natural environment. Where reinforced plastic sheeting is provided as a relief item for emergency shelter, it should be complemented with rope, tools, fixings and supporting materials such as timber poles or locally procured framing elements. Any such materials or defined shelter solutions should meet agreed national and international specifications and standards and be acceptable to the affected population."

Furthermore, in 1993, this manifesto was repeated and emphasized by the United Nations High Commission for Refugees:

> "Governments and emergency responders worldwide have historically had problems responding to emergency housing need following catastrophic events. Emergency housing is a recurring international problem, and cost-efficient, practical solutions are needed" (Winandy, 2006).

In addition, if man- made disasters such as war (which is the reason that millions of people are made homeless) were added to the above problems, the role of design research in this process and the responsibility of academics, in this process especially in schools of architecture, would be further defined. This thesis according to UN guidelines (Gostelow, 1999), developed existing equipment for sheltering in post-earthquake area by "Mobile architecture for natural disasters" because different kinds of disasters require different strategies. In addition, earthquakes in some cases could be the cause of other kinds of natural disasters, such as tsunamis, landslides. Earthquakes cause more damage, more economic loss and human loss of life (Chart 1.1 and 1.2); out of all natural disasters, earthquakes are the most frequent and reason of human lives losses, economic losses and collapsing buildings.

There are some fundamental questions relating to disaster responses in the United Nations International Strategy for Disaster Reduction (Van Niekerk, 2008). Therefore this research responds to the following research questions:

- What are the immediate architectural needs of people in natural disasters such as post-earthquake scenarios?
- How should we develop sustainable temporary structures and infrastructures to support immediate or longer-term needs in post-earthquake scenarios?

There are many immediate needs in post-earthquake scenarios for survivors at different scales such as water, food, shelter, evacuation, relief, medical drugs. However, all of these immediate needs are categorized in different groups by emergency services such as architectural responses, medical responses. All of these immediate needs are predicted in the United Nations Disaster Response Cycle (Van Niekerk, 2008). Emergency services, depending on the level of damage, have specific processes for each immediate need for survivors. This research identified disaster response cycle and different kinds of existing shelters for post-earthquake scenarios. Finally, develops possibilities through sustainable temporary shelters for these situations.

This research focuses on post-earthquake situations but before these post-earthquake scenarios, it is necessary to have knowledge about the nature of earthquakes, their sources/reasons, existing activities to develop immediate architectural responses and improvement to the quality of architectural responses toward the UNDRO[1] manifesto. Therefore, this Literature Review expands on different issues related to geophysics and the different architectural needs of survivors.

Aims and objectives

This research, after identification of immediate architectural responses and deep consideration on UNDRO problems in humanitarian crisis, aims to:

- Develop existing and new disaster solutions for self-construction shelters, erectable by earthquake survivors.
- Investigate the impact of these shelter designs in planning for immediate and post disaster situations.
- Develop these shelter designs for sustainable temporary and longer term architectural solutions for post-disaster periods (after earthquakes).

Different sections of Chapters Three to Six discuss different issues to respond to these aims and objectives. This research develops temporary sheltering through achieving mentioned aims above.

Emergency sheltering is a specific stage in the management of disaster response cycles and it adopts unique methods in different economies, cultures and at different technological levels in poor, developing and developed countries. It was a global strategy that was used for emergency sheltering post-earthquake in Japan, Haiti, Italy and Iran.[2]

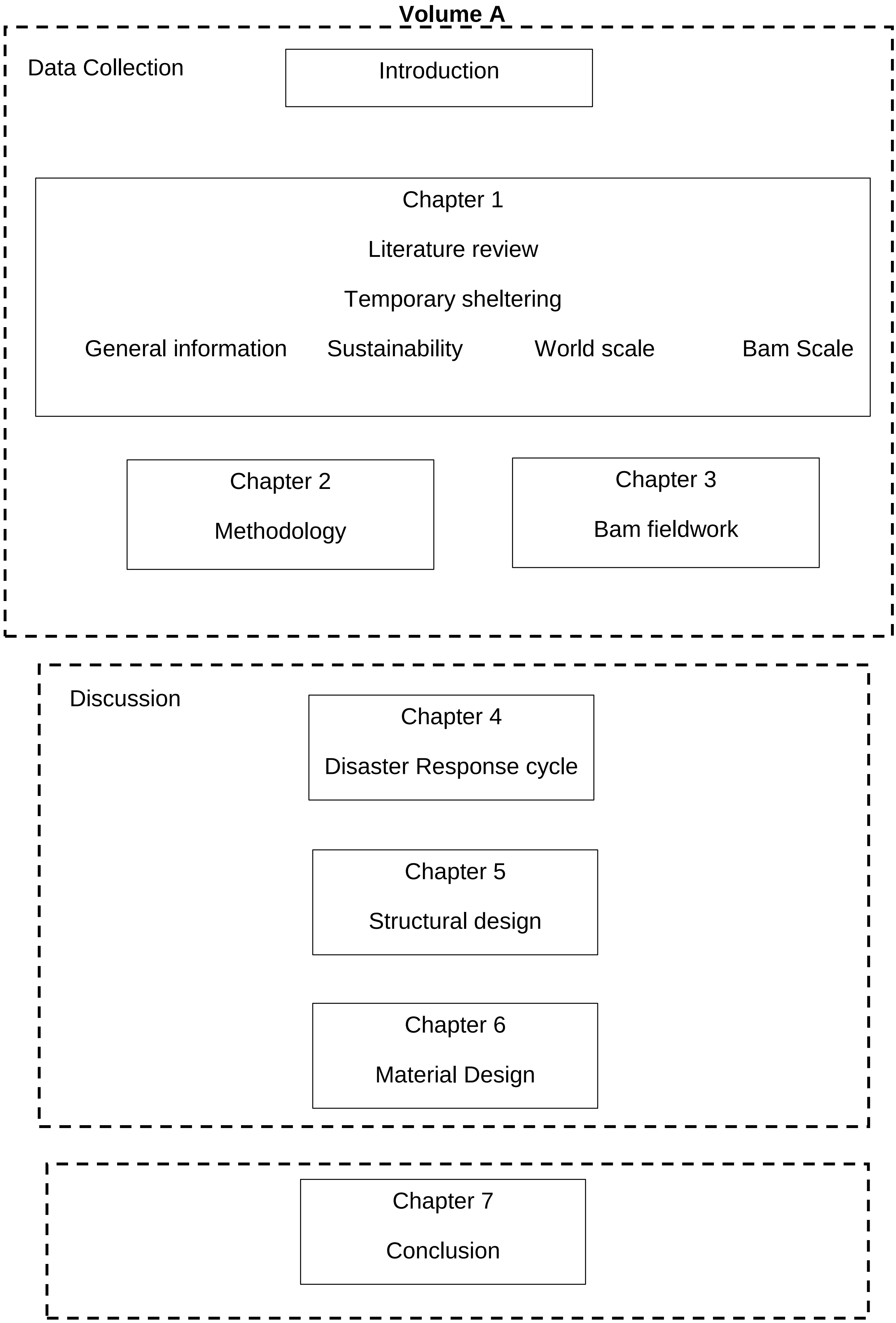
[1] United Nations Disaster Relief Organization.

[2] Conference Article 25/Manchester Metropolitan University, October 2010

This research, focuses on Bam to prototype a sustainable self-construction emergency shelters for survivors that can be used in both the short term and upgrade to long term temporary sheltering if it is needed.

After all of the investigations, interviews and data collections during the first year, it was decided to focus on the development of emergency sheltering through different methods and prototyping in actual scale. For further clarification and deeper consideration, this research consists of two volumes, including theory in volume A and practice in Volume B.

Volume A, as expanded on in the introduction, consists of six chapters and the outputs of these theoretical developments in emergency sheltering led to a different range of prototypes that are experimented with three groups of users to evaluate the efficiency and the potential of self-construction emergency shelters.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Conclusion

Chapter 1:

Literature Review

No interview in Lit Rev

Introduction

Chapter one as a Literature Review, supports directly and indirectly discussions in different chapters. It provides basic information about different chapters and expands on gaps in the earthquake response cycle or emergency sheltering. It compares different architect's views on developing emergency shelters and implications of the author on different topics.

This Literature Review is as below

- Sustainable development including sustainable development in emergency sheltering and sustainable development in Material science. This section explains the meaning of sustainability and how it can be applied in temporary shelter design for short-term and long-term.
- Earthquake studies explains existing knowledge and approaches on earthquake. It provides basic knowledge and a reference for sustainable temporary shelter design for post-earthquake scenarios. The approaches on earthquake can be as a natural event or natural disaster.
- Earthquake response cycle, discusses the process of earthquake response cycle and identifies the gaps. It expands existing strategies in disaster response cycle, scale of the responses, actions before and after earthquake and lessons from previous earthquake responses.
- Non-Governmental Organizations and their records which shows the process of sheltering in earthquake response cycle. It also expands existing equipment, principles of sheltering and their managements.
- The Bam earthquake and special architectural site conditions. This section discusses building materials in Iran, earthquake management and statistics, process of sheltering and restrictions because of UNICEF registered Bam citadel.
- Material science which expands basic knowledge material science and applied materials in emergency sheltering. In addition, it discusses about material sustainability and the gaps in this area.

It is important to mention that the ten sections of the Bam earthquake and special architectural site conditions provides general information about the situation of Bam before and after the earthquake and Chapter Three discusses and expands on field work in Iran and Bam for temporary sheltering.

For better analysis and understanding of earthquakes, this research collected different views and considered an earthquake as a natural event and as a natural disaster (cross ref). Viewing earthquakes as natural events helped to compare different earthquake scales and consequences of different earthquake scales while viewing earthquakes as natural disasters led to consideration of the existing equipment for emergency sheltering and lessons learnt from previous earthquakes.

During the first year of this research, information was gathered from multiple resources such as journals, books, documentary films and interviews to provide a complete base for the further research. By the end of the first year, it was concluded that the scale of the disaster response cycle and developments could happen through different fields such as management, economy, technology, culture in different scales nationally and internationally. However, this research has focused on the immediate architectural need and the stage of emergency sheltering in the disaster response cycle during post-earthquake scenarios.

1.1 Sustainable Development

Sustainable development is one the most important issues in contemporary educational targets and industrial developments. The Germans used the word “sustainability” for the first time in 1713 in forest industry. Their aims were to care about the eco-system and economy in their designs to save nature and ensure long-term use through efficient methods (Vegesack et al., 2000). Bill Hopwood says of sustainable development:

> “It is an attempt to combine growing concerns about a range of environmental issues with socio-economic issues. It is concentrating on sustainable livelihoods and well-being rather than well-having, and long term environmental sustainability, which requires a strong basis in principles that link the social and environmental to human equity” (Hopwood et al, 2005:39).

This research also identified the gaps in sustainability of emergency shelters in post-earthquake scenarios. This sustainable emergency shelter would be the result of proposing different areas such as material sustainability in emergency sheltering, emergency sustainability in emergency sheltering.

Industrial manufacturing between 1910 and 2010 increased by 100 times and energy consumption increased by 125000 times (Graedel and Allenby, 2010). A big part of this energy consumption comes from fossil fuels, which are finite sources of energy. This growth in fossil energy consumption has negative effects on sustainable development. The growth of energy consumption led to the creation of a world strategy to reduce greenhouse gases through time, which has affected the building industry (Appleby, 2011). This research proposes sustainable methods in lighting, heating, saving energy and simplifies transportation in emergency sheltering through designing creative sustainable self-construction emergency shelters as an output.

Regarding the growth of the world’s population, it is important to mention that existing human energy consumption patterns have affected CO_2 emission negatively. Statistics show that the average growth for the world's population over 50 years between 1950 to 2000, is 1.4 while the rate for energy use in the world is 1.7(Keyfitz, 1990)(ref). However, these rates in third world countries are higher and it affects the ecological system in those countries and the world's eco-system. During this period, the world is facing new environmental challenges such as global warming and climate change (Keyfitz, 1990). Material waste is directly linked to the world's population and with the growth of the world's population the percentage of material waste would increase.

This research, identified waste material options locally in Bam which have the potential to be employed in emergency sheltering. Waste material statistics could be different in developing, developed and poor countries but the United Nations has provided the world percentage and local percentage every year[3]. This is expanded upon completely in Chapter Six, Material Design for emergency sheltering. However, developing countries try to minimize their material waste while the amount of material waste in poor countries increases with population growth. All statistics are provided in Chapter Four to evaluate its potential.

Therefore, a sustainable approach in different industries, including the building industry, is vitally important. This research minimizes energy waste and maximise efficiency and sustainability in emergency sheltering through low and high-tech methods.

1.3.1 Sustainable development in housing: One factor, which affects sustainable development and is directly linked to the world's population, is housing and sheltering. As previously stated, the population on the earth, immigration to the cities and demand for energy are increasing. Therefore, it would affect sheltering and the building industry. Statistics show that (ref) the percentage of demands for sheltering in urban areas increased from thirty percent in 1950 and reached forty-seven percent in 2000. However, another statistic shows that during 2000 to 2010 demand for sheltering in urban areas increased more gradually by thirty percent. Finally, nowadays half of the people on the earth are living in the cities. Scientists (ref who?) predict that by 2025, with developments in technologies and societies more than 60% of the world's population will live in the cities (Apelian, 2012).

This growth in demand for housing in urban areas has occurred at the same time as the growth of numbers in natural disasters (Chart 1.1). Therefore, development in the building industry, in different scales including permanent sheltering, emergency sheltering and infrastructures, are necessary. As previously stated, with the increase demand in energy, CO_2 emission and migration to cities, sheltering in different scales

[3] The United Nations Statistics Division http://unstats.un.org/unsd/environment/wastetreatment.htm Access date: 16/05/2017

needs sustainable infrastructure and developments to cope with environmental challenges and potential natural disasters.

The sustainable approach in contemporary architecture focused on a different aspect of sustainability through the building industry such as sustainability in material use, energy, environment. The output and experience of these developments, which have the potential to be implemented in emergency sheltering, are identified and evaluated in this research. Collaboration of architects with sustainable designers and engineers with technological materials and methods can provide an opportunity to lead the building industry and sheltering methods towards more efficiency and sustainability (Ritter, 2007 and Nash, 1995). There is much research that relates to new techniques in contemporary architecture such as digital fabrication (Seely, 2004 and Steele, 2001) (ref) (new references). For instance, this research applied a laser cutter plotter for strut making and a 3D printer for joints in prototyping.

Iran as a developing country needs sustainable infrastructure which demand more energy to promote future sustainable developments including housing industry. As a result, sheltering will be more efficient in terms of energy and material efficiency. A sustainable development for sheltering needs innovation, creativity in design and methods of construction and a collaboration of engineering and architecture.

This research focused on a specific type of sheltering which is sustainable emergency sheltering for post-earthquake scenarios. During this research, the output of relevant research and appropriate examples in materials and methods or structural science were explored. For example, in the case of sustainability in energy, green energies such as solar panels have been implemented for military tents before and the potential of implementation of green energies in emergency sheltering are considered and explained completely in Chapter Four. In the case of sustainability in materials in emergency sheltering, the possibility of the application of reusable and recyclable material resources are considered for sustainable development in emergency sheltering and are expanded on in Chapter Three. With creative methods in architecture and engineering and collaboration of material science and efficient emergency shelters can facilitate the disaster response cycle.

1.3.2 Sustainable development in material science

In recent years because of sustainable developments in different areas and the fact that material resources in nature are limited, there are many methods for using fewer natural resources or long-term use such as recycling, replacing, re-positioning and conservation. These methods are explained and prioritized for emergency sheltering in section 6.5 of this thesis.

Recycling materials is an important issue to achieve sustainable development. The importance of recycling and repositioning is clearly understandable to prevent damaging nature, global warming, or increasing the cost of raw materials gradually.

These methods also have many advantages to save the environment, materials and money. Furthermore, the recycling of materials requires different technology. For example, different types of metals consisting of different percentages of chemical materials might be inefficient for recycling or cause late recycling or even cause environmental toxicity[4] (Tsuchiya and Sumi, 1972).

However, depending on the situation, other methods such as replacing and repositioning can be more sustainable rather than recycling. Generally, replacing and repositioning do not need complicated technology in comparison with recycling. Therefore, it saves time, energy and materials. All of these methods are being used in different developed and developing countries. For example, in repositioning, only the physical shape of a part is changed with the same material then it plays a new role with a new function. For instance, in the building industry, before demolishing buildings, different items such as timber or glass can be collected to be reused in different locations, although they might be resized the function of the item remains the same.

These methods can be a concept for development in emergency sheltering. For example, this research uses recycled materials as input materials for prototyping and as an output in the long term produce biodegradable waste materials which is recyclable to the environment without environmental toxicity. All of these existing sustainable methods are prioritised as an output for emergency sheltering with explanation.

This section provides general information about material waste on a global scale to show that the implementation of recycled materials and sustainable methods such as repositioning of materials have the potential which has not been considered before in emergency sheltering.

There are some essential requirements such as materials and energy for industrial developments in every country. Countries need energy and materials to run their industries and manufacturing sectors. However, because of some international protocols such as the Kyoto protocol there are concerns about environmental issues such as CO_2 emission (Oberthür and Ott, 1999). Therefore, countries are asked to develop their industries in an environmental-friendly manner. Depending on the main feed of an industry, different industries have their own manufacturing cycle, they start with essential requirements, which are raw materials, natural resources and energy. The diagram below shows the process of sustainable material use from input to output through the manufacturing process, with aluminium as an example.

[4] Environmental toxicity is a science of evaluating and preventing effects and pollution of chemical materials in our environments. It challenges different sciences and engages industries to protect environment.

The diagram below (Diagram 1.1)[5] is a manufacturing cycle for aluminium. However, in the cycle, recycling is predicted as a result of the international agreements such as Kyoto Protocol. With consideration of waste materials through different industries, this research can identify material options, which are more sustainable and environment-friendly.

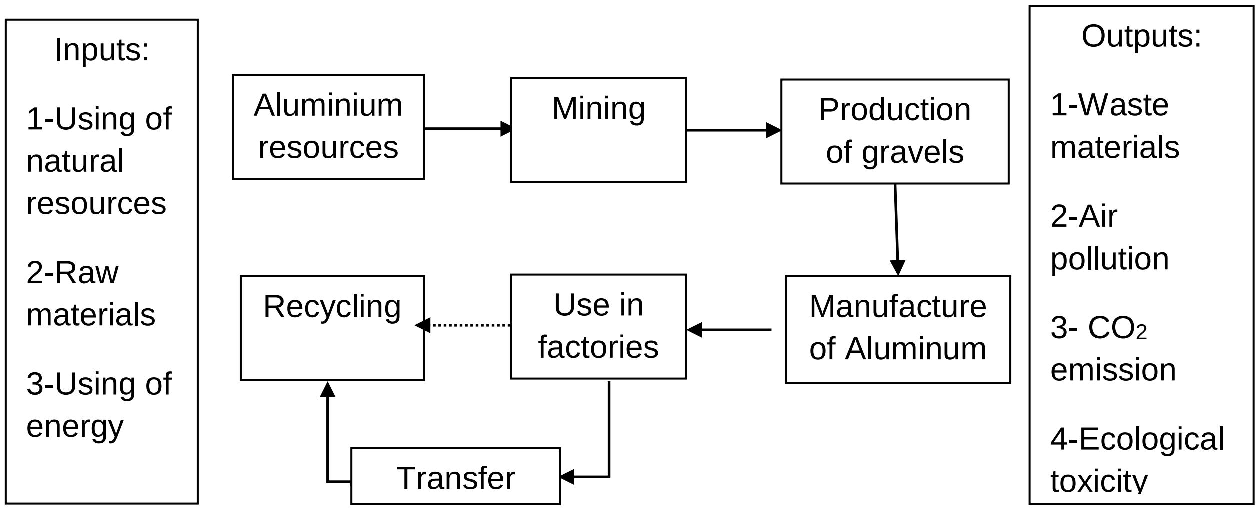

Diagram 1.1: *Manufacturing of aluminum from mining to recycling (manufacturing cycle).*

Parallel with environmental toxicity, material waste, energy consumption and sustainable developments, records and statistics prove that sustainable developments are not enough to cope with climate change or global warming as contemporary environmental challenges (Oberthür and Ott, 1999).

> "Recycling is an integral part of any waste management system as it represents a key utilization alternative to reuse and energy recovery (waste to energy)." [6]

The sustainable development strategy, depending on the situation and process of manufacturing, might have different priorities. For example, the diagram 1.2 is a general prioritization of sustainable methods in industries by Recycling Research and Technology, Earth Engineering Centre, Columbia University. In some industries, for example such as chemical industries, disposal of waste material might not be efficient therefore disposal would be in the prioritization of sustainable methods in the chemical industry. However, this research has its own prioritization sustainable method for

[5] Report EPA-530-f-11-05, U.S. Environmental Protection Agency, Washington, DC, November 2011

[6] Recycling research and technology website, earth Engineering Centre, Columbia University

emergency sheltering to develop emergency sheltering and contribute to the existing knowledge.

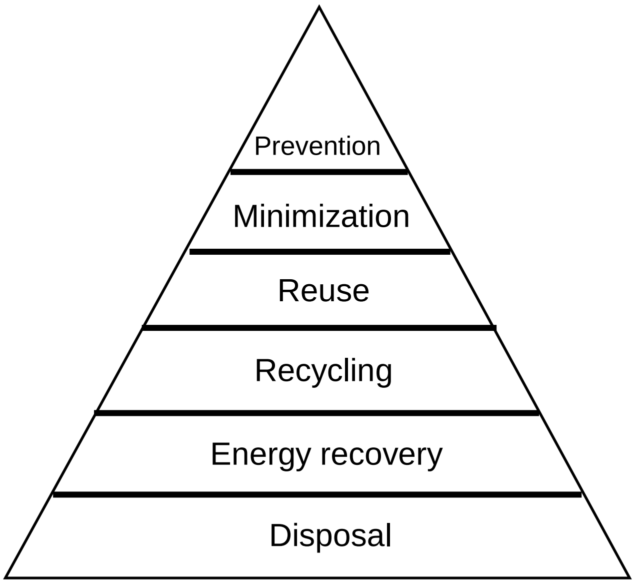

Diagram 1.2: *Prioritization of sustainable methods in industries. (Ref:http://www.seas.columbia.edu/earth/RRC/waste_material_utilization.html)*

Industries including building industry can increase their efficiency with prevention or reduction of their waste material disposal by moving towards recycling, reusing and minimization of wastage. This research applied disposed materials for prototyping. These materials are different materials including previously disposed cardboard. As figure 6.3 shows for a folded paper dome the author collected 215 sheets of waste cardboard.

> "Industry is increasingly aware that sustainable development is not only a business opportunity but also a challenge. There is a growing market demand for sustainable products, but regulatory stands can make these products difficult to develop economically."[7]

This research because of the special historical conditions of Bam post-earthquake scenario, and restrictions of industrial units around it had access to limited local waste resources such as cardboard factories. As the result this research designed its own prioritization diagram (ref) for more material sustainability in emergency sheltering.

1.4 Earthquakes studies

This section provides the basic knowledge about earthquake such as earthquake scales and discusses different issues related to earthquake with 2 different

[7] MRS April 2012. Materials for sustainable development. *Materials Research Society,* 37, 352.

approaches. Firstly, earthquake as a natural event, secondly earthquake as a natural disaster.

1.4.1 Earthquakes as a natural event: When a serious earthquake occurs, people lose their shelter where they eat, sleep and do their daily activities. An earthquake as a natural phenomenon causes a range of problems. These problems from one side are physical such as losing their house therefore they need emergency shelter and from the other side could cause psychological problems such as depression with losing their family members. There are different strategies for planning in different types of natural disasters.

There are different approaches to earthquakes as scientific or natural events, which are unpredictable. There are different NGOs that organize different activities before and after earthquakes to minimize the damage of natural events. Firstly, through a scientific approach, earthquakes can be expanded upon by “Geophysical science”[8] and related knowledge such as where/when an earthquake occurs. This view on earthquakes helps to focus firstly on different activities before and after an earthquake. Secondly, the research identifies the level of damage in different earthquake scales, different types of structures and different stages of sheltering.

The first step is knowledge about earthquakes. In simple words, an earthquake is the result of energy released from the centre of the earth so that the tectonic plates move. Earthquakes happen when stress, building up within rocks of the earth's crust, is released in a sudden jolt. The movement of rocks causes the ground to shake. The slipping of the rocks releases a lot of energy in fluctuating shapes that can move from the centre of the earth to surfaces in the same way that water creates waves when someone throws in a stone. Cracks along which rocks slip are called faults. A fault can stay deep in the earth and can break the exterior layer of the earth in different sizes and places, such as the Pacific plate. (Udías, 2005).

With identification of the edges of tectonic plates, locations with the possibility of earthquakes can be predicted, however timing of earthquakes with the existing knowledge and technologies is not possible. The identification of different locations with the possibility of earthquakes firstly can help this research to equip emergency shelters with appropriate material options for long term sheltering.

This approach will lead to a more sustainable emergency sheltering. For instance, in this approach, emergency services can predict long term material options for sheltering in which emergency shelters can be upgraded. Secondly, the prediction of these locations can affect transitional sheltering involving cultural issues to design appropriate transitional shelters related to the culture of the affected people and

[8] “Is the field of studies related to physic of the earth and its environment in space”.

survivors. The process of sheltering and the differences of stages in post-earthquake scenarios are expanded on in the Literature Review.

This research focuses on Bam as a case study, which is very important in terms of architectural heritage in Iran, which is located in the Persian plateau. Out of all earthquakes, the Bam Earthquake was chosen because of the personal experience of the author as a volunteer in the Bam earthquake and because of the special site and historical conditions of the Bam earthquake.[9]

Out of the different types of natural disasters, earthquakes have a unique disaster response cycle. Records and statistics show that earthquakes can occur at any location/ time but earthquakes follow a general pattern in any zone of the earth (Brumbaugh, 1999). It could be an advantage for this research to provide a specific range of emergency shelters for those areas according to their geographical location and climatic conditions of faults because it can affect material selection options for emergency sheltering. Alternatively, it might affect the structure or mechanism of self-erection emergency shelters.

The identification of geographical locations with the possibility of earthquakes, helps this research to categorize emergency shelters by selecting appropriate, sustainable material options and erectable/foldable structural options for self-erection emergency shelters by survivors. This research identified familiar, lightweight, low cost and sustainable material options for emergency sheltering in Bam such as palm leaves which are common material in building industry in Kerman and cost less to transfer because of climatic conditions, availability and familiarity. This research offers different ranges of material options, which are more efficient short and long term.

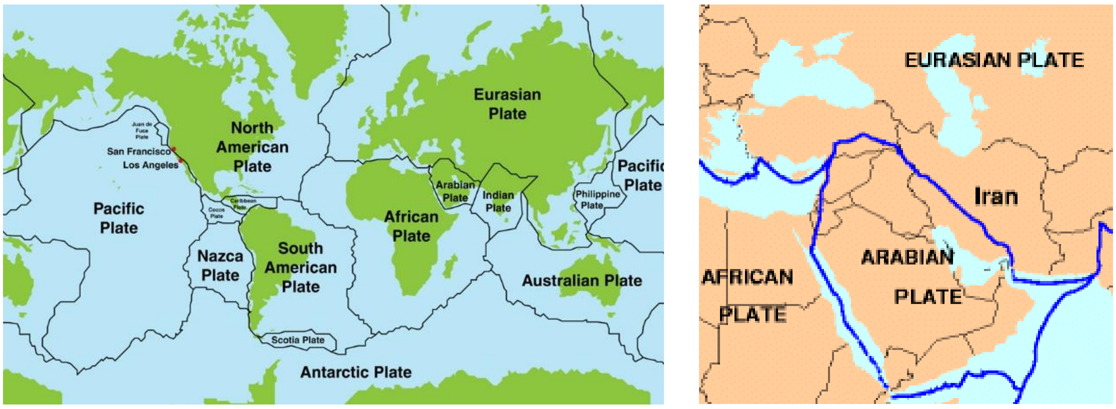

Figure 1.2: *Earth Tectonic Plates. Image Credit:* www.extinctiontheory.com, *Access date: 01/03/2017*

[9] Bam citadel dates from the Sasanian Empire 224-637 AD.

In addition, the other earthquake belt, called the Alpide, starts from the Atlantic and extends to Mediterranean countries such as Turkey, some areas of the Himalaya and Sumatra. This belt causes approximately 20 percent of the world's earthquakes including the Bam great earthquake (Iran), Roudbar earthquake (Iran), Tabas earthquake (Iran), Izmit earthquake (Turkey) (Brumbaugh, 1999). Identification of popular materials in the geographical locations of this earthquake belt can affect items of emergency sheltering. For example, palm-leaf can be a material option for emergency sheltering in Middle Eastern countries, which is a familiar and available material for sheltering. As previously stated, this research is not going to offer a unique prototype as an output of the research, but rather prototypes a different range of emergency shelters with the potential of upgrading to longer-term use in Chapters Three and Four.

However, earthquakes can affect people's lives in different ways. For example, earthquakes can cause loss of human lives and affect the region in other negative ways (Chart 1.2). Secondly, this view on earthquakes was the main reason for shaping the disaster response cycle and other human activities in different countries. Damage to infrastructure, such as public transportation, power and water systems, is the result of earthquakes. Statistics show that the numbers of natural disasters through history are increasing (Chart 1.1). For instance, in the chart below, the number of natural disasters including earthquake, storm, flood and other natural disasters between 1950 and 2000 are rising and fluctuating. This research focused on earthquakes and survivors' life conditions in post-earthquake scenarios. However, different types of disasters require a different strategies in the planning and response cycle.

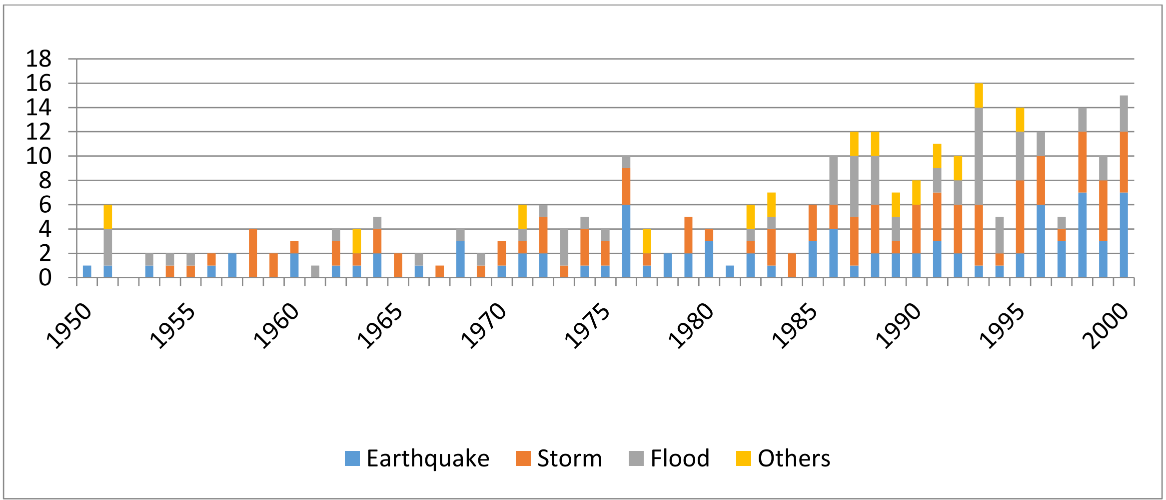

Chart 1.1: *Increasing number of natural disasters (Zhai, 2008)*

In the chart below (Chart 1.2) Zhai shows the number of economic and insured losses, during 50 years between 1950 -2000, are increasing gradually. In addition, as expanded on, migration from rural areas to urban areas in this period is increasing which increases economic and insured losses. Therefore, life and human economy on earth are affected by natural disasters and it is necessary to keep our equipment and strategies updated and improving as fast as the growth in numbers of natural disasters.

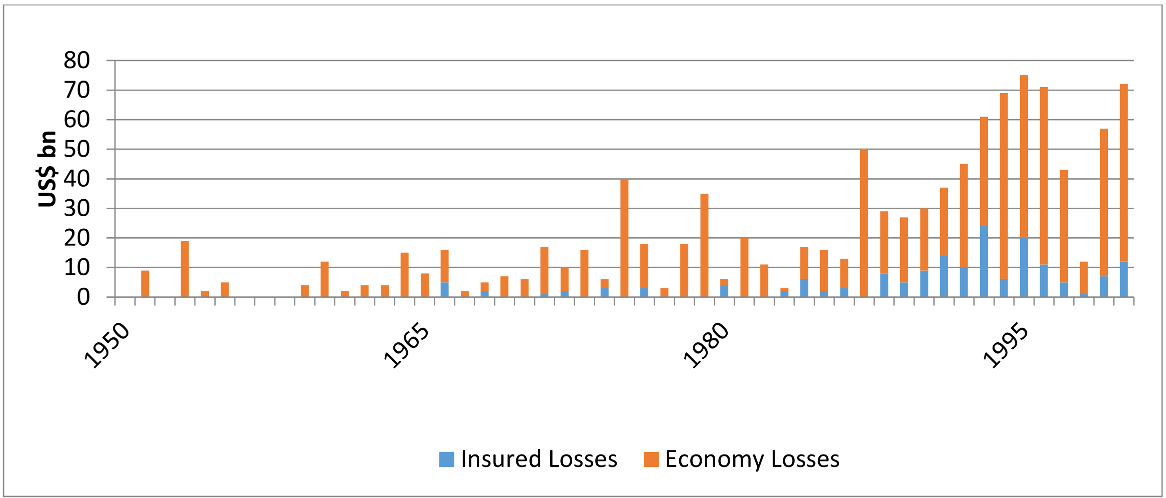

Chart 1.2: *Economic losses and Insured losses-Values for 1999 (Zhai, 2008)*

In contrast to Zhai's Chinese context disaster management in Iran is one of the important issues on which the Iranian Ministry of Housing and urban planning is working to minimise damages from different types of natural disaster. Ministry of Housing focused specifically on earthquakes as Iran is based within the earthquake belt. Zhai's data relates to the Chinese context before the Sichuan earthquake. Data and statistic for Iranian earthquakes are provided in section (Ref).

One of the important issues in the earthquake response cycle in Iran is emergency sheltering which needs a quick response over an area of 1,645,194 km^2 from North of Persian Gulf with hot and dry climate to the Caspian Sea with cold and humid climate in the north. Records from different earthquakes such as Quchan earthquake in 1893, Roudbar earthquake in 1990 and Tabas Earthquake in 1978 shows that the majority of people who survived from these earthquakes relocated their permanent homes from their cities for different reasons (Fallahi, 2007).

1.4.2 The scale of earthquakes

Generally, earthquakes are measured by Richter Magnitude scales. The Richter scale is a number, between 0 to 12, which calculates the power of shaking. The Richter scale is calculated through an algorithm, for example, the scale of the Bam earthquake was 6.5. The released energy of the Bam earthquake of 6.5 on the Richter was 31.7 times larger than the shaking power in the Kent (UK) earthquake in 2007, which was 4.5 on the Richter scale. The amount of released energy in each scale causes different damage, for example, the table below compares the amount of released energy in each Richter scale with released energy produced by exploding TNT (Brumbaugh, 1999).

Richter scale	1	2	3	4	5	6	7	8	9	10	11	12
	0.0005	0.01	0.47	15.08	476.87	15.09*1000	84.79*1000	15080.25*10000	476.88*1000000	15.11*1000000000	Never reported	Never reported

Shaking indoor ← → ←Building damage →

Table 1.1: *A comparison of released energy in Richter scale and tons of TNT (*Brumbaugh, 1999).

1.5 Earthquake response cycle

Generally, disaster response is a phrase for people who are in danger of losing their lives or economic damage from disasters such as earthquakes, floods, landslides. Throughout history, as charts 1.1 and 1.2 demonstrate, many natural disasters have happened and caused economic losses and insured losses. However, with development, many organizations have been shaped to prevent loss of life, and minimize loss of life and economic losses.

The immediate architectural need, such as emergency shelters or field hospitals in a post-earthquake scenario or other emergency situation is one of the fundamental immediate needs to save human lives (Davis, 1978). The Universal Declaration of Human Rights declares that to have a shelter either long-term or short-term is one of the basic human rights (UDHR, 1948).

> "Similar documents drawn up by multilateral organizations such as United Nations (UN) and the European Union (EU) and individual countries. These implications can be found in articles that refer to property, security and asylum." (Babister and Kelman, 2002:32).

The data collection of this research and experience of the author show that most emergency NGOs provide tents as emergency shelters. This emergency sheltering in a post-earthquake scenario comes from a unique response process by emergency NGOs who have a global strategy. In other words, emergency sheltering is one step of the response process which has its own process too. This emergency sheltering might happen in outdoor spaces such as school playgrounds or indoor spaces such as churches and sports shelters (Babister and Kelman, 2002).

As previously stated, the disaster response cycle depends on the type of disaster and the level of damage could be various and consist of different stages. For example, emergency NGOs use the same tents in emergency sheltering for different geographical locations with different environmental and climatic conditions (Mansfield, 2000; Babister and Kelman, 2002; Bolin, 1994). Documents such as (de Magaz et al., 2005), conferences and the website of Shelter Box Organization, as a manufacturer of the latest equipment for emergency sheltering, show that emergency NGOs use the same tents manufactured by the Shelter Box organization in different post-earthquake scenarios such as Haiti, 2010 as a poor country (Figure 1.8), as well as Abruzzo, Italy in 2009 (Figure 1.16) and other countries.

1.5.1 Existing strategies

In a post-earthquake scenario, responding to immediate needs is the duty of the local authority. Depending on political conditions and the economic level of the local authority, this response would be in different scales. Stephanie Jahnston, who had a presentation at the Article 25 conference in Manchester Metropolitan University in October 2010, expanded on her experiences in post-earthquake scenarios and the role of the local authority and people as an effective factor.

> "In the Haiti earthquake because of the weakness of local authority the role of international responses were more important than national responses, while in Italy the opposite occurred because local authority had technological knowledge and funding to manage nationally." [10]

All of the responses for natural disasters are in different scales, from the individual scale to the international scale (Thomalla et al., 2006). These immediate needs are in different fields such as feeding, sheltering and evacuating and are predicted in the disaster response cycle (Griekspoor and Collins, 2001). Emergency NGOs, depending on the level of damage, have specific processes for each immediate need of the survivors. This research firstly considers different earthquake scales and the level of damage to identify which level of damage requires emergency sheltering. Secondly, the research identifies disaster response cycles to focus on emergency architectural responses and different kinds of existing emergency shelters. As a first step, it is necessary to understand what people feel in an earthquake and how painful the scenario of a natural disasters is. Because of these questions in real situations, the best method was firstly to implement the personal experience of the author and secondly attending the Article 25 conference with professionals and managers of emergency services.

The Article 25 conference gave a comprehensive overview of the humanitarian sector and its models of operation, with specific reference to the problems surrounding sheltering and reconstruction. The most useful experience from Article 25 was the Haiti earthquake, which had a scale of 7 on the Richter scale. This presentation explained the concepts of architectural responses as one of the immediate needs, vulnerability,

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[10] Stephanie Jahnston was Article 25 manager in the Haiti disaster response cycle. She explained the process of response. She has been a member since 2008, on the completion of a Masters in development and planning. Originally part of the design team, she worked on the participatory aspects of Article 25's planning services in seven countries.

and earthquake response cycle, and the notion of disaster risk reduction, exploring the different stages of sheltering within its model. Finally, the author's view of the volunteering experience and presentations from this conference shaped some priorities and principles for this research from post disaster relief to rehabilitation, which is more permanent; these priorities are expanded in this chapter.

Stephanie Jahnston, in her presentation at the Article 25 conference, explains:

> "The process of responding in post-earthquake scenarios that emergency services are responsible for minimizing the effects of earthquakes and loss of human lives through an efficient earthquake response cycle."[11]

Therefore in every disaster response cycle firstly, site conditions such as geographical location, affected people, climatic conditions are not important because emergency sheltering has a similar strategy in every site or in other words it has global strategy. Secondly, the speed in making decisions and saving energy in such situations is very important and can help emergency services effectively to save human lives. Therefore, creative self-construction emergency sheltering can minimize the time of emergency sheltering with trained volunteers. Finally, emergency sheltering in post-earthquake situations is one of the most important requirements for survivors. The ease of transportation through the possibility of stacking up for storage or the implementation of lightweight materials can simplify national and international responses. This research, after expansion of the process of the disaster response cycle in this chapter, focuses on structural design, lightweight material design and an efficient method for emergency sheltering.

1.5.2 Scale of responses

There are several actions that should be taken, in relation to earthquakes by the emergency services. Some of these actions apply to after earthquakes and some refer to before earthquakes. Most of those actions that are before earthquakes are preparedness of equipment to minimize damage. All of these actions before and after earthquakes are in different scales, for example individual action or international action by governments. However, providing emergency shelters and preparedness is a small part of activities before earthquakes. As diagram 1.3 shows, those actions are in four categories, which are individual action, collective action, national action and international action. The strategy of emergency sheltering in all of the action scales are similar and global for post-earthquake scenarios, which means this strategy can be used in international action, national action, collective and individual action. The focus of this study is lightweight temporary shelters in post-earthquake scenarios to develop emergency sheltering for all scales of response. This global strategy in emergency sheltering can be developed through designing creative self-erection

[11] Article 25 conference/ Manchester Metropolitan University in October 2010,

prototypes by survivors. The outputs of the research are tested by different age groups through different workshops to assess the efficiency of emergency shelters by survivors.

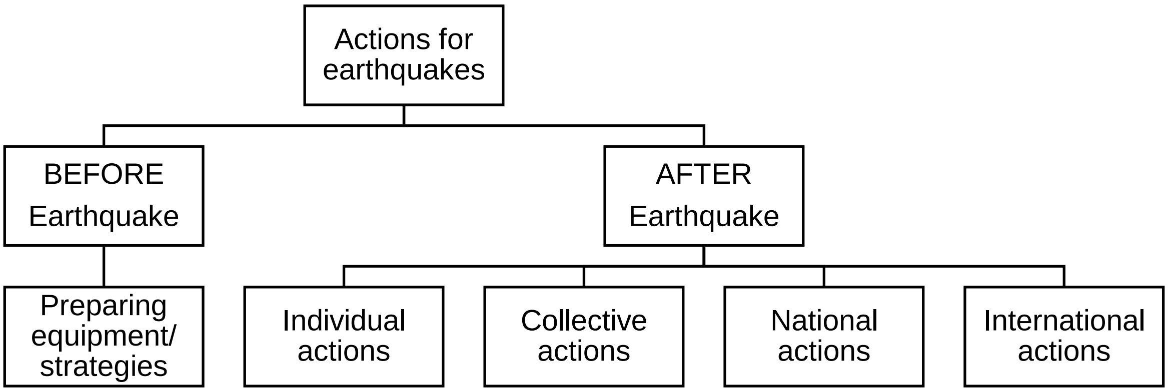


Diagram 1.3: *Actions following an earthquake (By author).*

1.5.3 Actions before earthquakes: There are many actions before earthquakes for food, water, sheltering and medical responses which emergency NGOs can predict in order to collect or store in advance. The process of emergency sheltering in the existing strategy is to manufacture foldable lightweight tents as emergency shelters and keeping them stored in different formats such as boxes or tubes before earthquakes. At the same time, NGOs and emergency services should train workers or volunteers with instructions to erect the tents. For example, a field hospital, which is usually in a bigger scale, has different instructions in comparison to assembling small-scale shelters. These activities, including prefabricating emergency shelters and training volunteers, are designed to be completed before earthquakes occur. As the figure 1.3 shows the Shelter Box Organization should train volunteers for 3 days in order to erect tent for survivors and to respond quickly to the immediate architecture needs. This is a before earthquake activity which needs budget, trainers, time and volunteers. However, output of this research with creative self-erection emergency shelters saves time, energy, costs as the simplification of emergency sheltering is very important through different low-tech and high-tech methods.

Figure 1.3: *Volunteers part of the three days training programme carried out by the Shelter Box organization, April 2013. (Ref: Shelter Box flickr account: Access date 22/11/2014)*

1.5.4 Actions after earthquakes: As stated, activities after earthquakes related to the disaster response cycle occur in four scales. Emergency sheltering as a stage from the disaster response cycle consists of four scales. Emergency sheltering can be by survivors, or it could be by donating or delivering from an individual to a person or site. Thirdly, it can be delivered by the local authority who are responsible for organising conditions or infrastructures to respond to survivors. Finally, all or part of the emergency shelters can be provided by international responses through different methods such as train, helicopter, plane to the post-earthquake sites. For all these scales in existing emergency sheltering trained volunteers are still needed to assemble and erect the existing tents. These trained volunteers could be national or international.

In the case study of the Bam earthquake, the scale of emergency sheltering equipment was international but for assembling and erecting emergency shelters, the local authority used volunteers on a national scale which majority of them were untrained volunteers. However, for some technological equipment such as hydraulic scissors from international responses some trained volunteers were sent to join the Iranian team to rescue people. These hydraulic scissors were useful to cut the frame of the windows or cutting concrete posts and beams.

1.5.5 Lessons from Earthquakes

Throughout history there are some lessons learnt from previous earthquakes, which come from the experiences of scientists, engineers, geologists in different earthquakes. Most of the lessons from earthquakes are developments and prevention plans, which refer to actions before earthquakes. This research mentions lessons learnt from the Bam earthquake and Chinese earthquake experiences which affected the government to plan nationally. Out of eight lessons, learnt from earthquakes from Ashtari (Ashtari, 2015) and Zhai's research (Zhai, 2008), some lessons may not be relevant to this research but some of them affect emergency sheltering. However, most of these lessons are related to management, prevention and how to minimize damage of the earthquakes.

Lesson 1: Up-Grading national standards

Scientists through geophysics, engineering and records of earthquakes in different areas, simulate the maximum and high-risk conditions to upgrade the national standards of building codes for earthquakes in different areas. Specifically after the Sichuan Earthquake the central government changed the national standards (Guo, 1998 and Zhai, 2008). Upgrading methods in the national standards of building codes usually affect the number of posts and beams in buildings and strengthens frames and foundations of buildings. Approximately all of these methods, including upgrading standards of the buildings, lead to expensive demolition, long-term reconstruction and property owner movements. Therefore, the government and different financial organizations should assist people (Comerio, 1997).

Upgrading national building codes for this research causes engineers and architects to re-consider implemented technologies, materials and methods in the building industry. Therefore, improvement of standards in the building industry causes less damage in buildings such as permanent shelters and therefore, less emergency sheltering in post-earthquake times. Even local authorities, with the upgrading and strengthening of a few buildings, can be used as crisis points in emergency situations. Therefore, upgrading the national code of buildings, in a small number or big numbers, in different areas will affect the disaster response cycle and specifically emergency sheltering.

The Iranian Ministry of Housing provided Iranian National Building Codes; this is expanded in section 1.7 of this Literature Review. However, because of the weakness of management in construction and ignoring construction rules and regulations, the level of damages was high in the Bam earthquake; this is expanded in section 1.7: The Bam earthquake and special architectural site conditions.

Lesson 2: Managements of national standards

Developments in the management of national standards could simplify the disaster response cycle and process of sheltering. A prevention plan or management plan could minimize the number of economic losses. In the case of the disaster response cycle, there are differences in the quality of services in the response cycle in developing and developed countries. Generally, in the situation when conditions are out of control and the level of damages are high, international emergency services respond quickly. It might improve the level of management and response in the post-earthquake scenario as it is a global process.

Before Bam earthquake Bam City Council had a management plan but after earthquake different places such as building of Bam City Council, Red Crescent building in Bam and most of the designed crisis points collapsed. However, Home Ministry with Kerman Red Crescent did management of the post-earthquake scenario.

Lesson 3: National preparation for earthquake by practice

The third lesson is to prepare more practical plans about disaster prevention for earthquake scenarios. Emergency services perform an important role in the practical plans and it would affect the quality of their services. Every year in some countries such as Iran, the government should hold many training sessions in different scales depending on the intensity of earthquake risk in the county. This training is based on individual and national actions (Zhai, 2008).

Emergency sheltering is one of the stages of the earthquake response cycle, which needs practice with existing equipment and strategies. Therefore, in countries, where the local government does not have enough budget to prepare training sessions the quality of emergency sheltering or training of technicians/ volunteers would be affected. However, this research developed self-erection emergency shelters with creative design to improve the conditions. These self-erection emergency shelters affect national preparation practice in every country and they allow local government to spend time and their budget for other trainings. The output of the research is based on low-tech traditional skills that maximize public engagement and do not need any technical skills. The aim of national prevention for earthquake by practice is to train volunteers and people for earthquake response. Therefore, the output of this research in long-term use is to be more efficient economically. The result of a practical plan with existing strategies can appear to improve the quality of services in actions before and after earthquakes by emergency services.

Lesson 4: Disaster prevention in regional planning and urbanism.

Integrating urban planning with disaster prevention was the next lesson from previous experiences. Nowadays cities and villages are becoming more responsive to earthquakes with the prediction of crisis points in different parts of cities. As the number of natural disasters are increasing and national building code and standards are upgrading, concern about this issue is an important factor for emergency services (Zhai, 2008).

Generally, the improvement of conditions after an earthquake depends on regional planning and land management. Therefore, first aid points including immediate architectural needs such as field hospitals, quick shelters for survivors, providing better conditions for landscape recovery and urban recovery are necessary in management (Cömert, 2004). There are some differences of strategy between developed and developing countries. In addition, problems of non-developed countries in natural disasters are linked to lack of an efficient management plan. Statistics show that on average there are three thousand deaths in every earthquake in developing countries, and less than 400 deaths in every earthquake in developed countries (Stephenson Jr, 2005).

Disaster prevention in urbanism can improve the quality of emergency sheltering by designing and predicting crisis points in the cities. The number of survivors and number of required emergency shelters depends on many reasons such as funds, infrastructure of the cities and the number of affected people. One of the advantages of this research is that the strategy of emergency shelter is global and has always been used for developed, developing and poor countries. For example records from Shelter Box as a manufacturer of the latest equipment of emergency sheltering, proves that the same tents were used in the earthquake in Japan as well as the earthquake in Haiti. Crisis points in the cities can simplify the disaster response cycle.

In addition, the Iranian Red Crescent was supposed to be central command for the Bam earthquake response cycle but even the building of the Iranian Red Crescent was seriously damaged and evacuated after earthquake. Therefore, Kerman Red Crescent based in centre of province in collaboration with architectural studios planned different sites for disaster prevention. For instance, they identified different empty lands after the earthquake as crisis points (Ashtari, 2015).

Lesson 5: Informing people is the most important part of risk reduction, with the latest equipment in cities and effective media for the public at the centre of risk reduction. (Zhai and Hu, 2008).

According to research by NIED in Japan two seconds early warning may reduce the risk to twenty percent of survivors, and only five second early warning may greatly reduce the risk by eighty percent of survivors (Wu and Kanamori, 2008).

Informing people is one of the most important parts of risk reduction. One of the reasons for the high number of human losses in the Bam earthquake was its occurrence at 5:26 in the morning. This time of the morning because of the late awareness of the affected people and lack of technology was the reason for the high number of human losses. There is no difference between developed countries and developing countries in this respect.

As the statistic above shows, early warning can decrease the number of survivors in a post-earthquake scenario and an early warning might help emergency services and NGOs to respond as quickly as possible but prefabrication of emergency shelters refers to actions before earthquake. However, an early warning will affect the delivering of emergency shelters to a post-earthquake scenario and will be useful to make volunteers aware to respond quickly. Some issues such as understanding where the next earthquake occurs, with existing knowledge still is not possible. Therefore emergency sheltering as a part of the disaster response cycle should be an action before an earthquake to ensure an efficient response. An early warning will affect quality, number of survivors and quality by quick response.

Lesson 6: Improvement of people’s attention in earthquake risk reduction (Zhai and Hu, 2008).

As previously mentioned, activities in terms of risk reduction could be in different scales from personal activities, collective actions, national actions and support from other countries (international actions). In addition, there are some activities to train volunteers for different sections in a post-earthquake scenario or train non-professional people what to do during earthquakes. For example, the author, experienced this during his education in elementary school when he was told; all students should hide themselves under the table or stay on the side of the corridor or door frames. These activities, such as regular prevention practices and simulating a post-earthquake scenario, affect the number of survivors in a post-earthquake scenario.

This research, with creative design as self-erection emergency shelter by survivors, develops emergency sheltering and maximise people's attendance in a post-earthquake scenario. Improvement of strategies in risk reduction cause better quality of services and efficiency in different aspects including saving time, money and energy. Therefore, the quality of architectural responses would improve.

This improvement of people's training needs budget and time, which in poor countries could be at a low level. However, at the moment with the existing strategy in emergency sheltering people do not play an important role in sheltering because most of the time trained volunteers are responsible for erecting their emergency shelters as field hospitals, field kitchens, and survivor's shelters with different sizes in post-earthquake scenarios.

Lesson 7: Improvement and creating an efficient national insurance system (Yayong, 2008).

Creating or improvement of a national insurance system is one of the most important policies from governments and local authorities but it is not relevant to this research and it does not affect existing emergency sheltering and developed emergency shelters.

Lesson 8: Implementation of technology for monitoring the disaster response cycle and earthquake studies (Yayong, 2008).

Nowadays, the latest technologies from different sciences such as geography and geophysics contribute to the disaster response cycle to make it quicker, simpler and more efficient. NGOs and emergency services are able to apply technologies such as GIS (Geographical Information System) technology (Greene, 2002) or GPS (Global Positioning System) (Kaplan and Hegarty, 2005; Kennedy, 2006) to monitor geographical and climatic changes of the earth to predict conditions. Therefore, the prediction of conditions and locations will provide many possibilities for emergency services. Satellite images are another example for local authorities and emergency services to improve and facilitate the disaster response cycle. In addition, this technological equipment can be used for early warning to decrease the numbers of human losses.

> "Mapping support during the early phases of response is critical, as responders and donors try to more clearly understand the situation on the ground. Without map action, the capacity to provide what is needed often simply does not exist".[12]

In the Bam earthquake different architectural studios such as Sharestan Co. in collaboration with the Army and Red Crescent applied technological equipment such

[12] UN Disaster Coordination Manager, Pakistan flood emergency 2010

as GIS and GPS for mapping Bam for reopening the roads and identification of empty lands for camping.

Lesson 9: Rationalize administrative management system of disaster prevention (Zhai and Hu, 2008).

Rationalizing the management system refers to the cultural and economic level of affected people in each country that is not relevant to this research. However, it affects directly on these kinds of research and developments, which contribute to natural disasters. Disaster management from the early stages to actions after earthquake are completely different in developing countries and developed countries.

Emergency sheltering is a global strategy for the emergency services. The level of culture or economy affects only transitional and permanent sheltering in the disaster response cycle, which are for long-term living in comparison with emergency shelters.

From all these lessons from previous experiences, the research can get an important output, which would be possible to use in methods of sheltering. The most important output of these lessons is to categorize people and emergency services in terms of technology. The research is considering public engagement with the creative design of a self-erection emergency shelter. It will respond to these lessons with people's attendance in Lesson 4, emergency services do not need trained volunteers for emergency sheltering because of the self-erection mechanism of shelters.

1.6 Non-Governmental Organizations

Generally, a non-governmental organization is the name of the organization, which does not belong to any local or non-local authority and acts independently. Secondly, most of these organizations are non-profit organizations. However, these NGOs might get funding from different sources including governments. These organizations can act independently and their actions do not depend on the actions of other institutions or organizations. NGOs in the disaster response cycle play an important role for survivors, providing immediate needs including immediate architectural needs in post-earthquake scenarios (Davis, 1978). Some emergency services, in the format of an NGO, have some priorities in responding depending on the type of disaster. The response to immediate needs in a post-earthquake scenario consists of different steps and stages where architectural responses are part of a long response cycle.

This research started collecting data related to emergency services from multiple resources in the library and NGOs engaged with post-earthquake scenarios. Secondly, the personal experience of the author in the real situation of a post-earthquake scenario was another important factor in this research to get familiar with different emergency NGOs. Thirdly, participating in the disaster response cycle conference at Article 25 and presentations from experienced NGOs managers, such as Stephanie Jahnston in Article 25, have provided information and structures of different NGOs. In addition, records shows that many NGOs have made developments in emergency sheltering equipment (Mansfield, 2000 and de Magaz et al., 2005) and managements of disaster risk reduction (Comerio, 1997). Most of these developments in emergency sheltering by NGOs are in the same format as existing emergency shelters, which are single units of tents. As previously stated, a manifesto from the United Nations in 1985 shows those developments, in terms of temporary shelters for survivors, are not efficient for different conditions (Gostelow, 1999). Existing and key developments from NGOs facilitate the disaster response cycle in terms of immediate architectural needs but most of those developments refer to transitional sheltering and a few cases in emergency sheltering, which are expanded in Chapter Three.

Most of the NGOs engaged with natural disasters design, build and manage projects to provide better shelter where there is disaster, poverty or need (Article 25 conference, Nov 2010). Generally, emergency services, before an earthquake or in some cases in the post-earthquake scenario, design new strategies for different situations. They need to work with aid organizations and other communities in different parts of the world to apply the quickest and most efficient methods to minimize loss and damage.

Figure 1.4: *An urgent meeting of international NGOs five hours after the earthquake in Haiti. The meeting happened in a tent as an emergency shelter.*

Image Credit: Stephanie Jahnston, Article 25

There are some international NGOs, such as the Red Cross, Red Crescent, that have governmental supports and some NGOs, such as Artcle25, with individual sponsors registered as a charity for different work in post-earthquake scenarios. In addition, there are some private architectural studios and organizations, which contribute skills nationally and internationally in earthquakes. Most of these companies have studios in different locations of the world. They design and reconstruct for some global challenges. Their skills can provide basic information of planning in post disaster scenarios or for reconstructing temporary and permanent shelters. This disaster response cycle has been improved by the emergency services at different times (Article 25 conference, Nov 2010).

The process of cooperating in an earthquake is:

Setting the scenario → The disaster response cycle → Sheltering

Diagram 1.4*: The process of cooperating in a post-earthquake scenario*

This research analysed post-earthquake scenarios systematically based on reality and experiences of professionals in emergency services.

1.6.1 Temporary sheltering

Engineers, designers and architects during last decades such as Fuller (Fuller et al., 2008), Sinclair (Sinclair et al., 2006), Pinero (Sorguc et al, 2009) and Daniel Ferrera (Antonelli, 2005) have tried to simplify and design methods of temporary sheltering. Generally, the idea of designing local emergency shelters does not match with the global strategy of emergency sheltering. However, this research designed a self-construction emergency shelters which is flexible for different conditions to maximize the use of sustainable emergency shelters.

Generally, there are three choices for temporary sheltering in post-earthquake scenarios.

- They stay at the post-earthquake scenario and live close to their collapsed houses.
- Survivors live far from their collapsed houses in public buildings such as indoor or outdoor sport fields.
- Survivors live far from their collapsed houses but they live as a group. In this case providing a temporary camp for survivors who left their houses is necessary. People in these conditions generally have to live as a big group for unlimited time (Fallahi, 2008).

1.6.2 Temporary sheltering approaches

There are three approaches in temporary sheltering which are like three points of a triangle. These three approaches are a design approach in temporary sheltering, a material approach and a survivor's approach (Keen, 2008).

- **Design approach:** a creative design approach is necessary to apply appropriate and efficient structural types and material options. One of the aims of this research is to design self-construction emergency shelter. Structural type plays an important role to increase efficiency. In this approach, international NGOs, such as the United Nations divide temporary shelters according to their physical shapes to filmic structures and surface structures (Keen, 2008).

- **Material approach:** The focus of this approach is on long term temporary sheltering. Materiality in the long term gets more important in terms of energy saving and sustainability. In recent decades material science in building technology plays an important role and there is different research which emphasizes the application of local materials and recycled materials (Keen, 2008).

This research applied familiar material options for short-term functionality and upgrading emergency shelters with local material options for long-term sustainability. Waste materials from demolished buildings and recycling are one of the areas explored in this research. There are different local material options and housing methods that are expanded in this research.

This sustainable approach is one of the existing approaches that in some developed countries is being applied in the building industry. One contribution to knowledge of this research is to apply this method of material design in emergency sheltering in post-earthquake scenarios. For example, Japan is one of the developed countries implementing this method in the building industry.

- **Survivors approach:** This research maximised public engagement in post-earthquake scenarios with the simplification of emergency sheltering through application of familiar forms and materials and erection mechanisms. This research believes that lack of public engagement in emergency sheltering is one of the weaknesses of the existing strategy for emergency sheltering. In addition, personal experience and other documents such as practical sessions from NGOs to train volunteers (Figure 1.3) demonstrate that survivors should wait for trained people to erect shelters for them.

1- "In order for UN to respond effectively to major, sudden onset disasters it is crucial that experienced staff are fielded quickly to back up country office staff. It is unacceptable that there are long waits for staff in key areas such as training. It is also crucial that key operational personnel in human resources, finance and supplies are in place equally quickly."[13]

1.6.3 Cold Climate Emergency Shelter

Scientists and designers prototyped a cold climate emergency shelter at the University of Cambridge with chemical insulation materials. The output of the research was ideally for cold climates but this shelter has the same the problem as the existing emergency shelters and needs trained people to assemble the tent. Even the shelter structure needs technical skills because of material insulation. However, the output of this research with mathematical calculations, computer simulation, and climate simulation evaluates insulation of the emergency shelter with manufactured materials such as "Miraflex", "Crown Universal", "Rockwool Ductwrap", "Quiet Zone" and Web Dynamic Composite Spun Polymer Quilt (Mansfield, 2000). These materials were used in different parts of emergency shelters such as roof, floor, and walls and can make this shelter resistant to -20 Celsius (Mansfield, 2000).

[13] UNICEF IRAN BAM EMERGENCY PROGRAMME 2003 – 2006 INDEPENDENT EVALUATION FINAL REPORT / Executive Summary Page v

Figure 1.5: *Example of an emergency shelter designed for cold climates in University of Cambridge in February 2000* (Mansfield, 2000).

Below are technical details of the cold climate material options for the emergency tent. Two major problems of these materials are heaviness and their high costs while the existing emergency tents are low cost and made from lightweight materials. As the table below shows the cost of the roof of the cold climate emergency shelter is in different range from £47.81 to £121.16 for 7 square metres in the UK, while emergency sheltering with recycled materials are more efficient and sustainable compared to high-tech chemical materials. These prices are for a research in the University of Cambridge in February 2000. Prices in 2017 are provided by author in the UK.

Material Option for sheltering	Required thicknes	Roof cost in 2000	Roof cost in 2017	Roof packed vol	Roof weight
"Miraflex" resin-free fibre	0.15m	£47.81	£51.2	0.256m³	30.21kg
"Crown Universal" glass fibre Ductwrap	0.11m	£97.83	£110	0.930m³	73.60kg
"Rockwool Ductwrap" mineral fibre	0.11m	£121.16	£140	1.004m³	114.00kg
"Quiet Zone" closed cell foam	0.14m	£69.84	-	2.196m³	13.69kg
Web Dynamic Composite Spun Plymr	0.10m	£70.00	£75	0.190m³	13.70kg

Table 1.2: *Material logistic table of cold climate shelter (Mansfield, 2000).*

1.6.4 Principles of temporary sheltering

Providing the minimum required space for daily activity is a priority in emergency sheltering. These required spaces for daily activity, according to the United Nations guidelines, are: a place for preparation/cooking food, storage, and sleeping/ recovering/ seating area. In a unit of emergency sheltering for a family of four the standard is a minimum of 12 square metres and for a transitional shelter the standard is 24 square metres for a family of four. A tent of 12 square metres with a separate toilet should be located in a field of 100 square metres. Below is a diagram of a single unit tent provided by the United Nations. [14]

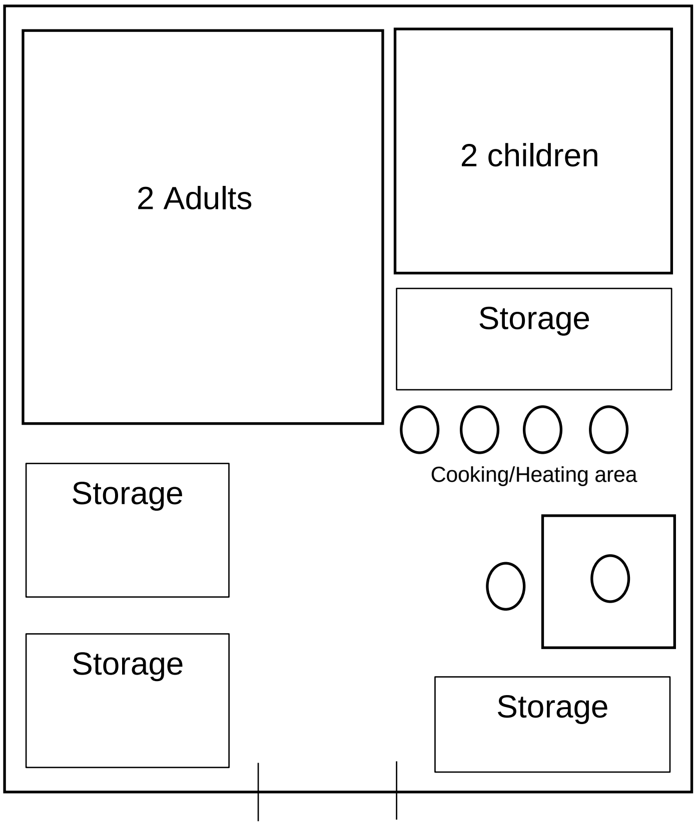


Diagram 1.5:

Diagram of a single unit tent. Required space is three square metres per person. It could be in circular plan or rectangular plan

(Ref: UNHCR/InerWorks, 2004)

The basis of the categorization of people for emergency sheltering in post-earthquake scenarios is to determine the number of affected families and societies for better quality of responding. The disaster response cycle from the United Nations has been designed for the groups mentioned below. In this categorization families are between 4-6 persons, societies are 16 families/ 80 people, a village is four societies or 320 people, a block is 4 villages or 1,250 people, sectors are 4 blocks or 5,000 people and camp is 4 sectors or 20,000 people.

1 Family	Base of group	4-6 people
1 Society	16 families	80 people
1 Village	4 societies	320 people
1 Block	4 villages	1250 people
1 Sector	4 blocks	5000 people

[14] *Ref: UNHCR/InerWorks,2004*

1 Camp	4 sectors	20000 people

***Table 1.3**: Groups for temporary sheltering (UNHCR/ InterWorks, 2004)*

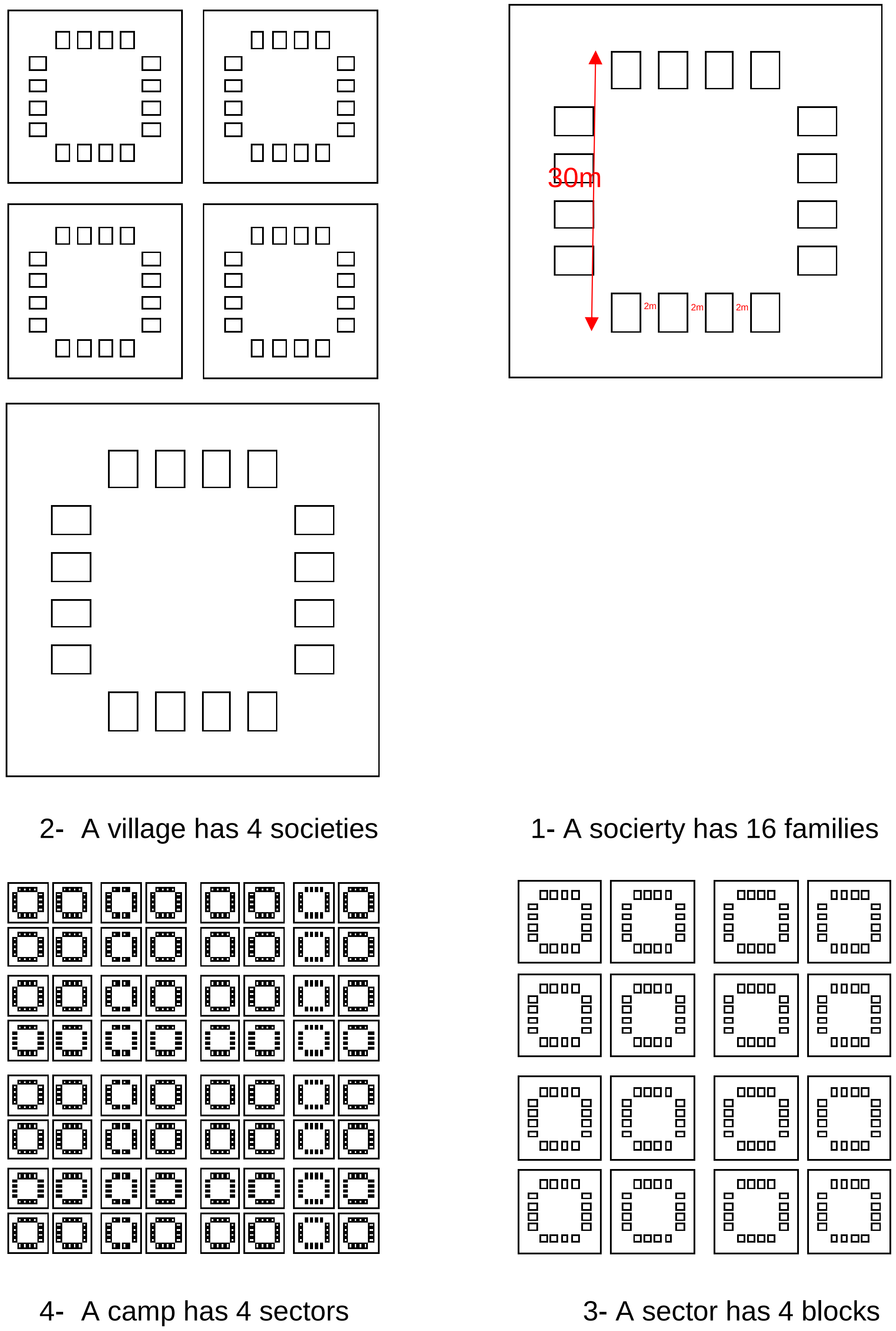


***Figure 1.6:** Categories of temporary sheltering (UNHCR/ InterWorks ,2004)*

There are instructions for shaping a camp or block for survivors in a post-earthquake scenario. One item is the location of each unit in terms of distance and view over other units. It is preferred that the entrance of units should not have a direct view with other units. Secondly, these units must be close to pedestrian paths and emergency routes. Thirdly, all units should have easy access to toilets. Finally, in terms of health and safety, each tent should have safety distance with emergency routes (Fallahi, 2007).

1.6.5 Camp planning patterns

Generally, planning patterns for emergency sheltering in camps are in three groups. The first pattern is linear, the second is grid pattern and finally there is a circular pattern. There are different patterns such as polygon plans, star patterns but because of the possibility of a quick response to different units, adaptability to post-earthquake scenarios and better or equal quality of services to each unit from emergency services, the three patterns that are mentioned below are the priority for planning in a post-earthquake scenario (Fallahi, 2008).

- Linear pattern plan: In this pattern, all units would be erected and placed in a line with a minimum distance of two metres from each other. These lines generally should be located close to car and pedestrian routes to ensure that the quality of emergency responses in all units are equal.

Figure 1.7: *Linear pattern plan after Earthquake in Bam*
(Ref: www.kermankhabar.ir Access date: 13/04/2015)

- Grid pattern plan: This planning pattern is a very familiar pattern, specifically in urban design. This pattern consists of different routes in horizontal and vertical directions and every block can be divided to smaller parts. Most of the first aid points, or other services such as health and safety, can be located in main junctions of main routes. It has many advantages; the most important advantages of these planning patterns would be familiar pattern and easy pattern to plan. Secondly, it has the possibility of prioritizing routes according to their importance. Thirdly, with the increasing number of survivors there is the possibility of unlimited extension of the camp. Finally, the quality of emergency responses would be equal because of division of blocks and sections. This type of planning does not have a central point.

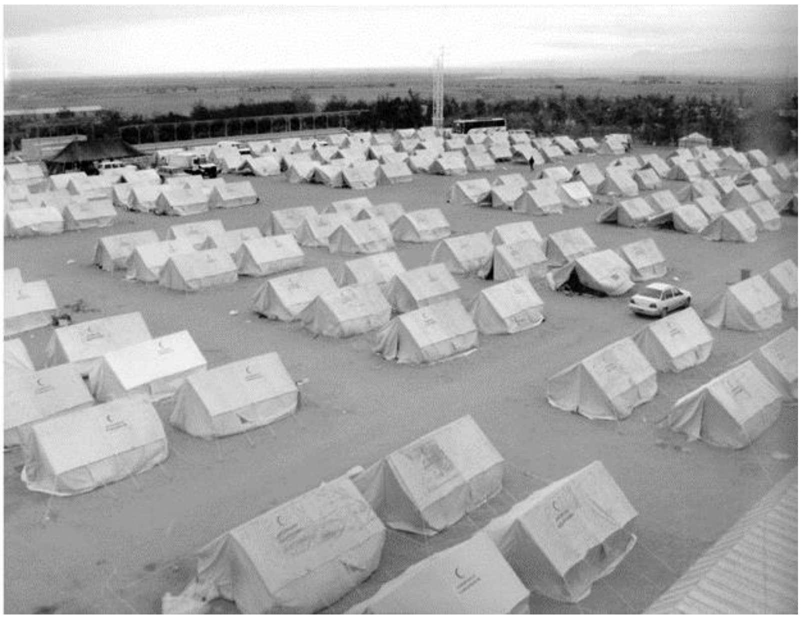


Figure 1.8: *Grid pattern plan after Bam earthquake (Abadi, 2004)*

-Circular pattern: In this planning pattern, the camp has a central point and primary routes start from this point. This type of planning means that there will be a quick response from the central point to different parts of the camp. The most important advantage of this planning pattern is centralizing different facilities. Secondly, other services such as showers or toilets can be in a point with an easy access. The disadvantages of this pattern for planning could be centralizing all of facilities in one point might cause difficulties in management and secondly in earthquake sites with varied topography it is not possible to implement.

1.6.6 Management of the crisis points for temporary sheltering

There are different factors, such as time and the location of earthquake, which are effective in the management of the camps for emergency sheltering in post-earthquake scenarios. Data collection and data sharing between emergency organizations are the most important stages in the first few hours after earthquakes.

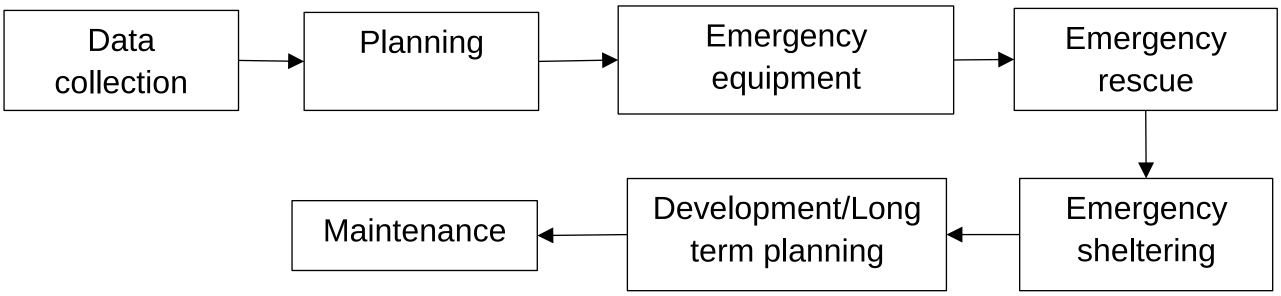


Diagram 1.6: *Stages of emergency response from NGO view (Fallahi, 2007).*

The creative and efficient management and planning in a disaster response cycle in a post-earthquake scenario can save survivors in different conditions. However, in some countries local authorities do not have enough power to manage and control everything. For instance, some areas with difficult access cause problems for delivering emergency services in planning and makes management more difficult. Access to appropriate and efficient information is a key point. Some of the management factors for short/long term planning are listed below (Fallahi, 2008).

- Access: Access to the crisis points in post-earthquake scenarios is the first condition of a crisis point to deliver first aid and other health and safety services to survivors. Secondly, easy access to crisis points can simplify the connection of survivors to their families, friends and relatives or other local people who are in better psychological conditions. Sometimes local authorities, because of economic or political reasons, decide to make restrictions for access in some parts around the crisis points as a post-earthquake camp. Therefore, they accommodate survivors in suburbs of the cities where they do not have easy access and it imposes many costs for land preparation, security and making routes for cars and people.

- Protection: As has been mentioned before, adequate shelter is one of the fundamental and basic human rights; protection of survivors from the elements is part of this basic right. In the post-earthquake scenario, the location of temporary sheltering to maximise protection would be very important.

- Security: Securing survivors and their properties in a post-earthquake scenario is very important. An effective factor for more security is the selection of a good location for temporary sheltering as a camp.

- Environmental concerns: this issue concerns the health of the local people caused by using natural resources during temporary sheltering in post-earthquake times. In recent years, environmentalists and naturalists are concerned about accommodating a lot of survivors in unpredicted and ad-hoc areas, such as camps, as they can cause damage to the environment in the short and long term. In this case, selecting the appropriate location for a temporary sheltering camp and avoiding grazing lands or agricultural lands are important. Using natural resources such as cutting trees for heating or cooking, increasing the number of insects or rats because of the bins and using chemical materials for disposing of them are all examples of damaging the environment (Fallahi, 2008).

1.6.7 Strategies of temporary sheltering

Considering previous experiences in temporary sheltering in Turkey, Johnson (2005) expands on different strategies for temporary sheltering that many NGOs and governmental organizations had engaged with to select the most efficient strategies for temporary sheltering. He believes that people who play important roles in a post-earthquake scenario should predict and plan most of the preparations in advance and get ready for the earthquake. Basically, pre-planning a strategy would be more efficient and planning a strategy when people are in an emergency situation would be more difficult and causes more damage even in a planned strategy for a post-earthquake scenario. Emergency NGOs and local authorities should evaluate the situation before responding to see how efficient that strategy can be. If it is efficient enough, emergency NGOs can start responding straight away. If it is not efficient, they can reconsider some factors of their strategy. The diagram below demonstrates the process of planning a strategy for a post-earthquake scenario (Johnson, 2005).

The most important factors of temporary sheltering include climate, location, types of temporary sheltering, pre-earthquake conditions and vulnerabilities, regional and local issues, long-term effects of temporary sheltering, project procurement planning and construction time, permanent reconstruction strategy and timing (Diagram 1.7) (Johnson, 2005).

The most important advantage of this diagram is its simplicity to manage a post-earthquake scenario. This diagram, similar to an algorithmic pattern is expandable and changeable after an earthquake. In addition, it can be adapted to the situation for more flexibility and efficiency but it is not an efficient diagram for planning a strategy before an earthquake and all factors of this diagram can be used for data collection of an existing situation of an earthquake site.

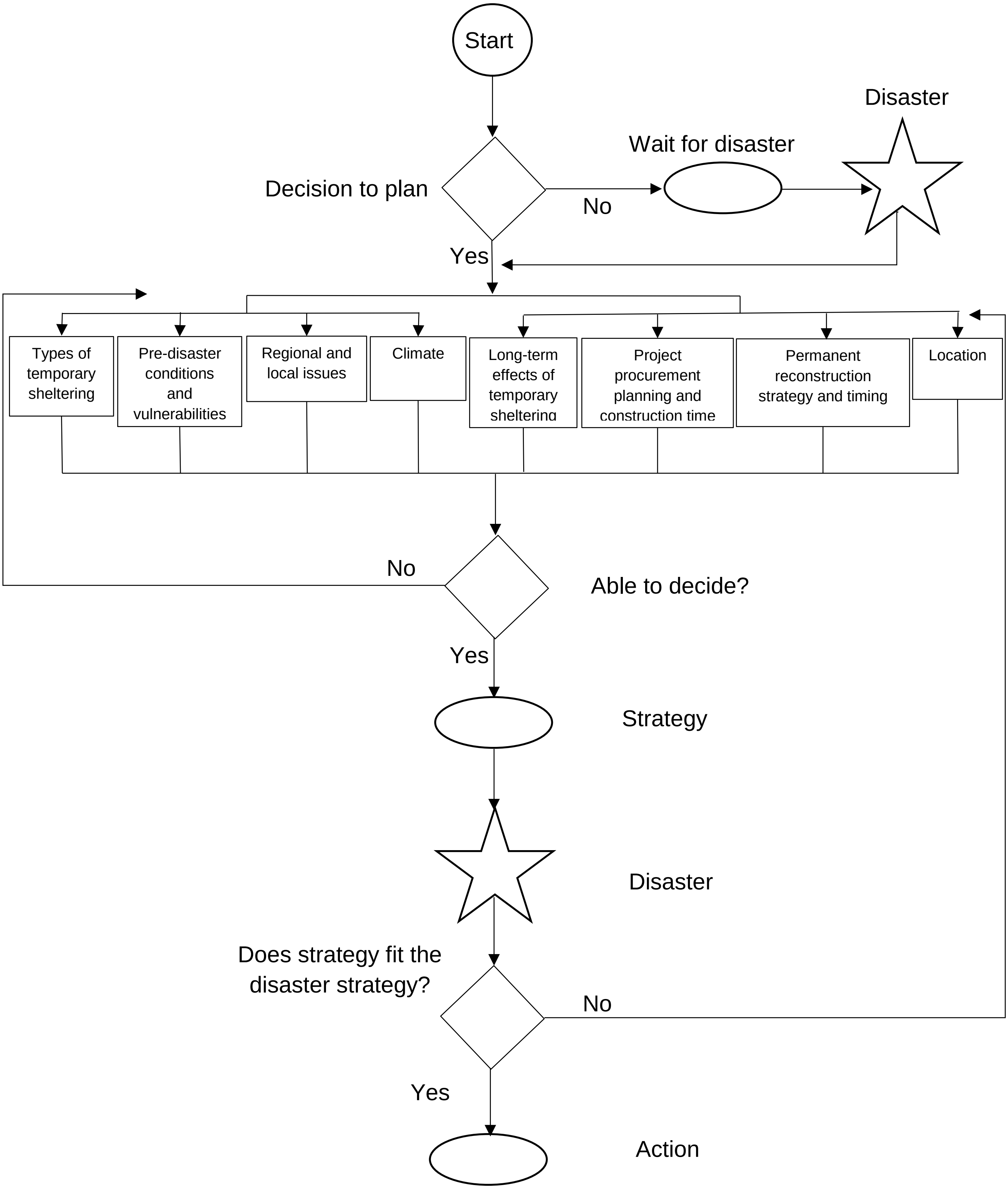


Diagram 1.7: *strategy of temporary sheltering (Johnson, 2005).*

1.6.9 Requirements of temporary sheltering

Transitional shelters are generally single units that are multi-functional and are designed for long term temporary sheltering. For example, a cabin is designed to use up to six months in a post-earthquake scenario but generally months or even years after they are in good conditions and it can be re-used again.

There are different factors that are effective in selecting a site for temporary sheltering. These factors are access to water resources, land per capita, car and pedestrian access to site, location of site for business, security, landform, access to green spaces, culture/ tradition of survivors, waste material management, and health and safety.

> "Selection of best location for temporary sheltering needs a lot of data collection, analysis to evaluate factors that affect selecting a site for temporary sheltering." (Fayazi, 2011:9).

Dr Fallahi in his book says that site selection for temporary sheltering is related to different factors such as number of survivors, access to site, topography, soil conditions, climate, natural resources around the site and the requirement of that site in the future. However, some of these items are related to technology and application of technology can simplify site selection (Fallahi, 2008).

- Water resources: Easy access to water resources is an important factor for site selection that should be considered. Water resources could be river, water shaft, qanat[15]. It is important to provide the standard amount of required water in a post-earthquake scenario, required drinking water per person per day in a post-earthquake scenario is 15-20 litre and the distance of each emergency shelter to drinking water tank should be more than 500m (Fallahi, 2008).

- Land per capita: According to the standards of United Nation High Commissioner for Refugees (UNHCR) land per capita is 45 square metres that includes emergency shelter, paths, services and green spaces. However, in camps with no green spaces land per capita would be 30 square metres per person (Fallahi, 2008).

- Access to site: Possibility of easy and secure routes to a post-earthquake camp is vitally important for quick response to the site. According to UNHCR standards width of primary paths should be 10-12 metres and width of secondary paths should be 6-10 metres. Finally, lighting of primary routes are necessary but lighting of secondary paths are optional and are advantageous.

[15] Qanat is a UNESCO registered traditional method of transferring water in ancient Iran that is still used to transfer water. (Ref: http://whc.unesco.org/en/list/1506, Access date: 25/11/2016)

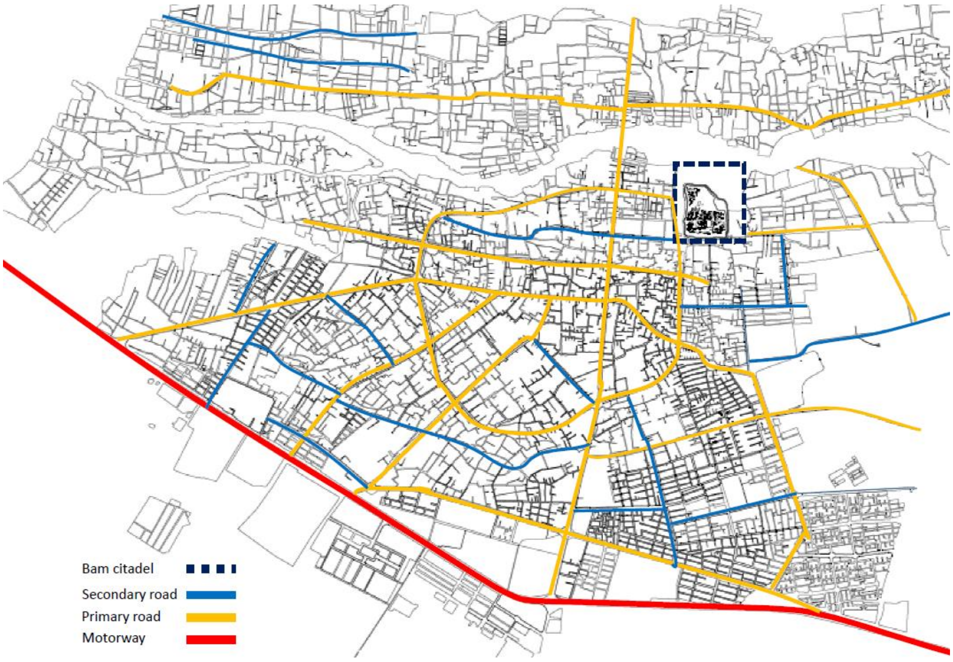


Figure 1.9: *Car access in Bam after earthquake (Abadi, 2004).*

- Site location for business: During evaluation and analysis of a site for crisis point site selection, it is important to plan business transportation in the long term. Therefore site identification, neighbourhood and business potential of site is very important. Another important factor for site selection would be concern about flooding potential and avoiding selecting a site in risky areas for a post-earthquake scenario. Finally, another factor for site selection is easy access to natural resources.

- Security: interior and exterior protection of the crisis point is important. There are different risks in post-earthquake scenarios such as robbery, kidnap, rape. Locating a crisis point with identified boundaries with different types of fences or walls can increase security in a camp. The other option for security would be protection of a site with volunteering in different shifts.

- Topography: Slope percentage for a post-earthquake scenario should be between 2% - 6%. Site topography between 2%- 6% causes easy transferring of surface waters to out of the camping site. Post-earthquake camping sites with more than 10% slope causes problems with emergency sheltering and transportations and sites based in a land with less than 2% slope are in a risk of flooding in rainy seasons.

- Green spaces and energy resources: Selecting a site neighbouring a green space with tall trees can reduce the risk of flooding. Secondly, wood can be used as a heating or lighting material in emergency situations.

- Culture and tradition: Post-earthquake camping site should not be located in or close to national, international parks, cultural, ancient and religious sites. In addition, concerns about cemetery locations and funeral ceremonies in different locations is another important cultural or traditional factor.

- Waste management: Waste materials in a crisis point as a post-earthquake camp can cause different types of disease and illness. Therefore, waste management is very important in both the short term and long term. Bins should be removed from earthquake camps and should be disposed far from earthquake camps and natural resources that might be used during temporary sheltering. In every earthquake camp portable bins with a capacity of 50 tons and 100 litres for every 4 -8 emergency shelters should be supplied (Fallahi, 2008).

- Health and safety: Post-earthquake camps without clean water or regular cleaning can increase the risk to health and safety. With providing food and other emergency equipment in every crisis post in post-earthquake times, it is important to pay attention to personal and group hygiene and to keep the water clean. There is an instruction by UNHCR for health and safety for different aspects, such as water, toilets, personal hygiene, group hygiene, waste management, collecting surface waters that are not related to this research. Survivors who live in an emergency shelter need a toilet and the standard for an emergency camp is one unit toilet for every 1-3 units emergency shelter. This toilet can have a tank or can be connected to a pipe to transfer out of the post-earthquake camp. If the toilet cabin benefits from a tank, it should be at least 1.5 metre away from the water tank in every location on the post-earthquake camp.

1.6.10 Process of site selection for temporary sheltering

One important issue in planning is to plan different lands for different uses. Linking neighbourhoods and how they act and react, predicting crisis points in emergency situations, predicting easy access to natural resources, simplification of business are issues in this process. Therefore, the diagram below with all of different requirements and predictions is designed for post-earthquake campsite selection.

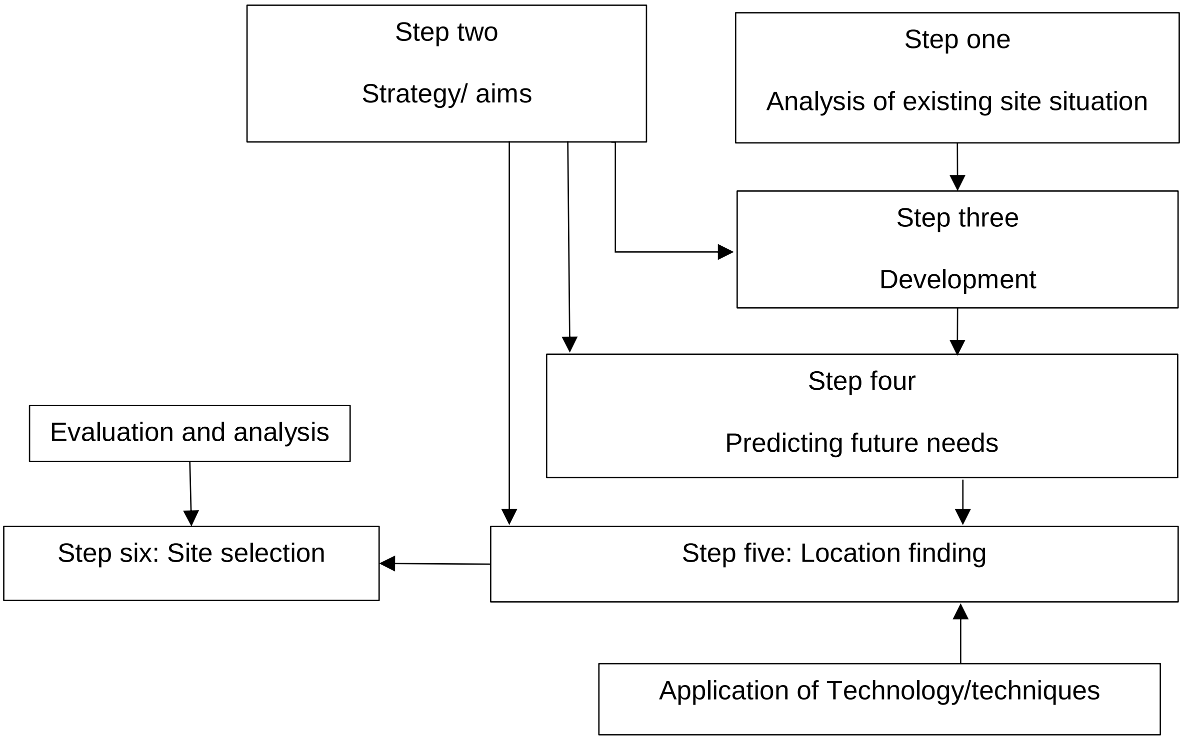


Diagram 1.8: *Process of site selection for temporary sheltering (Fallahi, 2008).*

- Step one- analysis of existing situation: Analysis to identify sites, which are not at risk of earthquake, flooding, landslide is an important step. Secondly, urban development plans use existing sites that have more potential to be a place for post-earthquake camp.

- Step two- strategy and aims: In this step, aims and prioritizing lands for different uses can be defined. In this step uses of other land neighbours, transportation possibilities, car and pedestrian access to site should be evaluated. Additionally, climate condition, water and air pollution of the site are important. Consideration with all of these mentioned factors, minor and major aims and strategies can be selected. Aims and strategy affects all of developments, predicting future needs and location finding.

- Step three- development: Development is to analyse for future possible disaster events. In this step under specific frameworks from selected strategies, different plans can be proposed to maximise efficiency and minimise risk.

- Step four- predicting future needs: This step is covering survivors' needs in the short, mid and long term. Emergency needs are the priority. Experience and lessons learnt from previous earthquake play important role to predict survivor's needs. Every post-earthquake scenario with different geographical location, climatic conditions effects the survivor's need in the long term. Therefore future needs for a post-earthquake scenario through lessons learnt from previous earthquakes would be predictable.

- Step five- location finding: for location finding different factors such as technological equipment including GIS and GPS, experience of local people, local authority information can simplify location finding.

- Step six- site selection: From all of the evaluations, analysis and decisions collected from different data sites for temporary sheltering, site selection of where survivors should live for the short and mid-term.

This six step for site selection includes all of the low and high tech methods which works in every geographical location. Even information can be collected from developed countries through different methods such as satellite technologies to transfer poor countries. In recent years scientists and designers use GIS, GPS and available analysis systems to find lands for different uses such as agriculture, building industry and the disaster response cycle to make it quicker, simpler and more efficient.

Emergency NGOs are able to apply technologies such as GIS, Geographical Information System technology (Greene, 2002), or GPS, Global Positioning System (Kaplan and Hegarty, 2005; Kennedy, 2006), to monitor geographical and climatic changes of the earth to predict conditions. Therefore, the prediction of conditions and locations provide many possibilities for emergency services. Satellite images are another example for local authorities and emergency services to improve and facilitate the disaster response cycle.

1.7 The Bam earthquake and special architectural site conditions

This section expanded upon building types and material options for housing in Bam, the earthquake response cycle and the process of temporary sheltering in the Bam post-earthquake scenario. Chapter Three is research fieldwork related to survivors' architectural needs and the process of temporary sheltering in Bam. This part provides general information about housing, sheltering material options and other collected data relate to Bam in the Literature Review.

The Bam earthquake was a national tragedy. Iran is located in an earthquake belt and the Bam earthquake acted as an alert for central government to use national and international lessons to predict an efficient management plan for future earthquakes, as if there was a similar earthquake in other cities in Iran, the human loss and economic losses with this level of earthquake would be similar.

Bam earthquake occurred at 6.5 on the Richter scale on Friday 26th December 2003 5:26am in local time. The centre of the earthquake destroyed the 2,700 year old Bam citadel[16] and the city of Bam in seconds. More than thirty thousand people lost their lives (Ramazi and Jigheh, 2006).

Bam earthquake caused 70%-90% of residential houses, governmental buildings and hospitals to collapse. Bam earthquake with this scale of damage was a shock on a national and international scale.

Out of the different buildings in Bam, buildings of brick or clay completely collapsed or were seriously damaged, while buildings with steel or concrete structures, which meet Standard No 2800, did not collapse. In Iran, there is a national building codes "Standard No. 2800"[17] (No, 2005) that construction under those rules, regulations and policy can save economy and human losses in Iran. Different structural reactions in an earthquake from different buildings is expected in different earthquakes but according to "Standard No 2800", regular inspections from relevant organizations during construction and concern about climate and geography design could minimize damage. It showed that efficient building codes, rules and regulations are not enough and building control and inspections are needed (Ramazi and Jigheh, 2006).

The Bam earthquake has been one of worst earthquakes in the history of Iran, which is one of the experiences in terms of lesson learnt. Records and geophysical science

[16] "The base of the ancient city was constructed in the Sasanian Empire period (224-637 AD) and while some of the surviving structures date from before the 12th century, most of what remains was built during the Safavid period (1502-1722). During Safavid times, the city which occupied six square kilometres was surrounded by a rampart with 38 towers. Bam prospered because of pilgrims visiting its Zoroastrian fire temple (dating to early Sasanian times) and as a commercial and trade centre of the famous Silk road".

HARPER, P. O. & GALLERY, A. H. 1978. The royal hunter: Art of the Sasanian Empire, Asia Society.

[17] Iranian Code of Practice for Seismic Resistant Design of Buildings-1988

shows that it is not the last earthquake for Iran but it can be the last experience of major human loss and economic losses. This can be achieved by short-term, mid-term and long-term post-earthquake management plans through coordination between different organizations and providing minimum requirements.

1.7.1 Building materials in Iran

During the last decade, there has been lot of earthquakes in Iran that have caused much damage(Ref) see table 1.4. For instance, except Bam, which was expanded upon one of the earthquakes with major damage was Manjil earthquake in 1990 with 7.3 on the Richter scale that caused thousands of deaths (Abadi, 2004).

Rural areas: Generally, through looking at earthquake records in Iran, it can be defined that statistics of human loss in rural areas are higher in the east and south of Iran. Clay, mud bricks and brick buildings are used in these areas as these local materials for sheltering are popular. Statistics show that rural buildings in the east and south of Iran are in risk of serious damage in earthquakes more than 5.5 on the Richter scales.

Urban areas: Urban buildings, which are constructed by bricks and cement, would be more stable in earthquakes up to 6.5 on the Richter scales. Generally, earthquake resistance of those buildings, which are made by bricks and with no steel and concrete frames are not stable in earthquakes more than 7 on the Richter scale. Even with the best methods of construction buildings with brick structure still are at high risk of building damage (Abadi, 2004).

Year	Location	Richter scale	Human loss
1911	Ravar	6.2	70
1924	Kaj-Derakht	5.8	780
1924	Quchan	7.3	3,200
1931	Salmas	7.2	2,500
1936	Mazandaran (North)	6.3	500
1941	Birjand	6.1	680
1948	Doost abad	6.8	200
1962	Boeen Zahra	7.2	12,200
1968	Dasht bayaz	7.4	N/A
1968	Ferdows	6.4	N/A
1972	Fars	6.9	5,000
1977	Kerman	5.7	665

1978	Tabas	7.3	18,000
1990	Manjil	7.3	30,000

Table 1.4: *Number of Human losses in earthquakes for eastern and southern Iran where local materials for sheltering is mud-brick and clay similar to Bam (Abadi, 2004).*

Figure 1.10: *Earthquake damages to contemporary (top) and traditional building in Bam(down) (Ref: http://www.earth-auroville.com).*

Generally, popular building materials in Bam were affected by climatic and economic conditions that caused the construction of different types of buildings. Some building materials were manufactured in Bam and some of them were imported from other cities. Building materials in table below are categorized by different building parts.

Building Part	Material for contemporary buildings	Material for traditional buildings
Wall	Clay, wood, brick, cement, Lime plaster, plaster	Clay, wood, mud-brick
Ceiling	Clay, palm leaf, Concrete beams, Bricks, cement	Clay, palm leaf
Building foundation (if applies)	Concrete, steel	N/A
Connections	Concrete, metal	wood

Structure	Concrete, steel, wood	wood

Table 1.5: *Building materials in Bam (Abadi, 2004).*

Application of these readily available material options in Bam is expanded in Chapter Six. Some of these materials are low-cost, environmental-friendly and sustainable. In addition, some of these materials of contemporary buildings are local and some of them imported from other cities such as steel but 100% materials of traditional buildings are local. Furthermore, these material options have potential to be reused after the Bam earthquake. It is expanded in Chapters Three and Six.

1.7.2 Earthquake management in Iran

Every year there are many natural disasters around the world. Out of 40 types of natural disasters, 31 types are registered in Iran. Out of 31 registered types of natural disaster, earthquakes are the most frequent disaster, which happen many times in different scales during year. Through time and specifically during the last decades the number of natural disasters have increased around the world. Increasing numbers of natural disasters have caused increasing numbers of human loss and economic losses.

In Iran, approximately 48,000 people lost their lives between 1960 – 1981 in 38 earthquakes. On average, every earthquake has 1264 human loss. These statistics caused a change in national building codes in Iran, consideration on earthquake management and sheltering in different scales. Generally, crisis management and specifically earthquake management should not start in post-earthquake times. History shows that crisis management needs to look back and use previous experiences (Abadi, 2004).

Statistics show that through time Iran on average has had many serious earthquakes. Furthermore, Iran is experiencing different types of natural disasters because of the huge territory and different climatic conditions in different parts of the country. Therefore, it is important to manage the crisis through efficient disaster response plans and fluency on different conditions to minimise human and economic losses.

There are different issues for earthquake management, therefore many NGOs that were formed in Iran are active but government or local authorities in Iran have a problem trying to match and link these activities together. Most of these problems have political reasons.

Principles of earthquake management are:

- Central command
- Telecommunication in post-earthquake scenario
- Statistics and data collection
- Rescue teams
- Different supplies

- Temporary first aid points
- Camps
- Instructions after first 8 hours to first week

Central command: Iran has experienced many disasters as well as 8 years of war with Iraq. They experienced disastrous leaderships, prioritizing reconstruction locations and different management methods. All of these actions are based on central command. Nowadays the Iranian government applies those experiences for earthquake reconstruction and Red Crescent would be responsible for emergency responding. Generally, they divide survivors to smaller social groups for more resilient and better earthquake response and efficient management.

Telecommunication in post-earthquake scenario: telecommunication in post-earthquake scenario plays an important role and has advantages that are mentioned below

- An efficient and quick data collection.
- Easy coordination and leadership between different medical and rescue teams.
- Connecting emergency NGOs to central command and base in post-earthquake scenario.
- Linking central command to local authority for providing urgent requirements.

Statistics and data collection: setting in the scenario and an efficient earthquake response cycle needs accurate data collection and damage evaluation. There are different methods of data collection, planning and questioning.

Providing statistics for economic losses and human loss in every post-earthquake scenario depends on collection of statistics before an earthquake. Local government should have information on the number of people, families, houses, animals and they should collect and provide these statistics regularly.

After an earthquake, different identification teams should report in different areas of post-earthquake scenarios and start working at the same time with rescue teams. They should constantly provide information about landscape recovery, number of deaths, injured people, homeless survivors, road situations, water and food resources.

Rescue teams: It is important to mention that military forces, such as the army, are one of the most well-organized teams that can simplify earthquake response cycles. In situations when emergency NGOs are damaged or not available, armies can respond quickly to simplify responding. Advantages of military forces are

- Levels and trends that they apply for different missions,
- Centralized command team,
- Own food supplies
- Transportation equipment,

- Possibility to use military knowledge in landscape recovery,
- Telecommunications and roads reopening,
- Providing security in un-secure sites,
- Access to organisation equipment and individual equipment.

Different supplies: Different supplies in post-earthquake scenarios can be divided to two parts:

Firstly, different supplies for survivors in post-earthquake scenario: parallel with rescuing trapped people, providing water, food and emergency shelters are necessary. These supplies should be packed before and ready to deliver through different methods. It is important to prepare different shelters as a store in post-earthquake scenarios. Helicopters, trucks can deliver their goods to stores.

Secondly, different supplies for emergency NGOs: supplying different equipment for temporary settlement, good food and other equipment for responding are vitally important. Every person as a volunteer or trained responder can only stay in a post-earthquake scenario a maximum of 4 weeks because of psychological reasons.

Temporary first aid points: the structure for medical response are as below:

- Emergency response branches in different parts of earthquake scenarios to deliver minor medical treatments after rescuing.
- Emergency centres; which cover and support different emergency response branches with more medical services.
- Field hospitals: There might be a few field hospitals in a post-earthquake scenario, which are necessary to erect quickly. These field hospitals should have the space for surgeries and radiography. Injured survivors should be transferred to nearest hospitals to the post-earthquake scenario, which are permanent hospitals for short and long treatments.

Camps: Generally, camps for earthquake survivors, are the places for those who are displaced. They might live there temporarily for a short or long time as a group. The process of temporary sheltering with existing strategy and equipment would be tents for emergency sheltering and porta cabins for transitional sheltering. It would be better to predict some areas around the city as crisis points for temporary sheltering, leisure, educational, sport fields. Previous experiences of the Red Crescent show that each camp should have maximum capacity of 5000 people in a maximum 50 hectares to control and manage camps easily (Cuny and Intertect (is it organization?), 1977). (ref)

1.7.3 Requirements for temporary sheltering

Temporary sheltering is one of the important stages of the earthquake response cycle and it is based on the important factors that are mentioned below (Fayazi, 2011).

- A camp for temporary sheltering in a post-earthquake scenario needs a manager to deliver and organize different services and responsibilities. The manager of the camps in post-earthquake scenarios are firstly responsible to deliver foods, water, shelter, issuing ID cards. Secondly is responsible to train volunteers for different tasks for different emergency situations including deliver and improve other services.
- Access to camps through a unique and private route is vitally important. This route can be connected to a main road. It can improve camp independence.
- Need for public spaces such as schools, prayer rooms, playing grounds
- Need for private spaces such as family shelters
- Services such as health centre, security centre, educational centre these last three items can improve camp privacy for survivors.
- Every camp should have access to minimum natural possibilities such as topography, river, water.
- Seasonal location changing should be predicted for camping.
- Before selecting a site for temporary sheltering different climatic and geographic conditions should be considered for any fire in future.
- Different families, groups and social structures should be identified

1.7.4 Strategies of site finding for temporary sheltering in Bam

For temporary sheltering in Bam, local authority and emergency NGOs had four strategy options.

The first strategy was to have one camp for temporary sheltering an efficient strategy for small cities and villages. Therefore, providing security and other services for 60,000 people in a camp was not possible.

The second option was to move people to a different point, and move survivors to other cities and villages to benefit from different urban and rural services. This option for Bam was not a good choice because there is no city close to Bam and other villages had collapsed. In addition, there is the possibility of damage to infrastructure of those cities and villages through moving more than the capacity of that city or village. Furthermore, there would be cultural shock for host-village/city that would cause social and security problems.

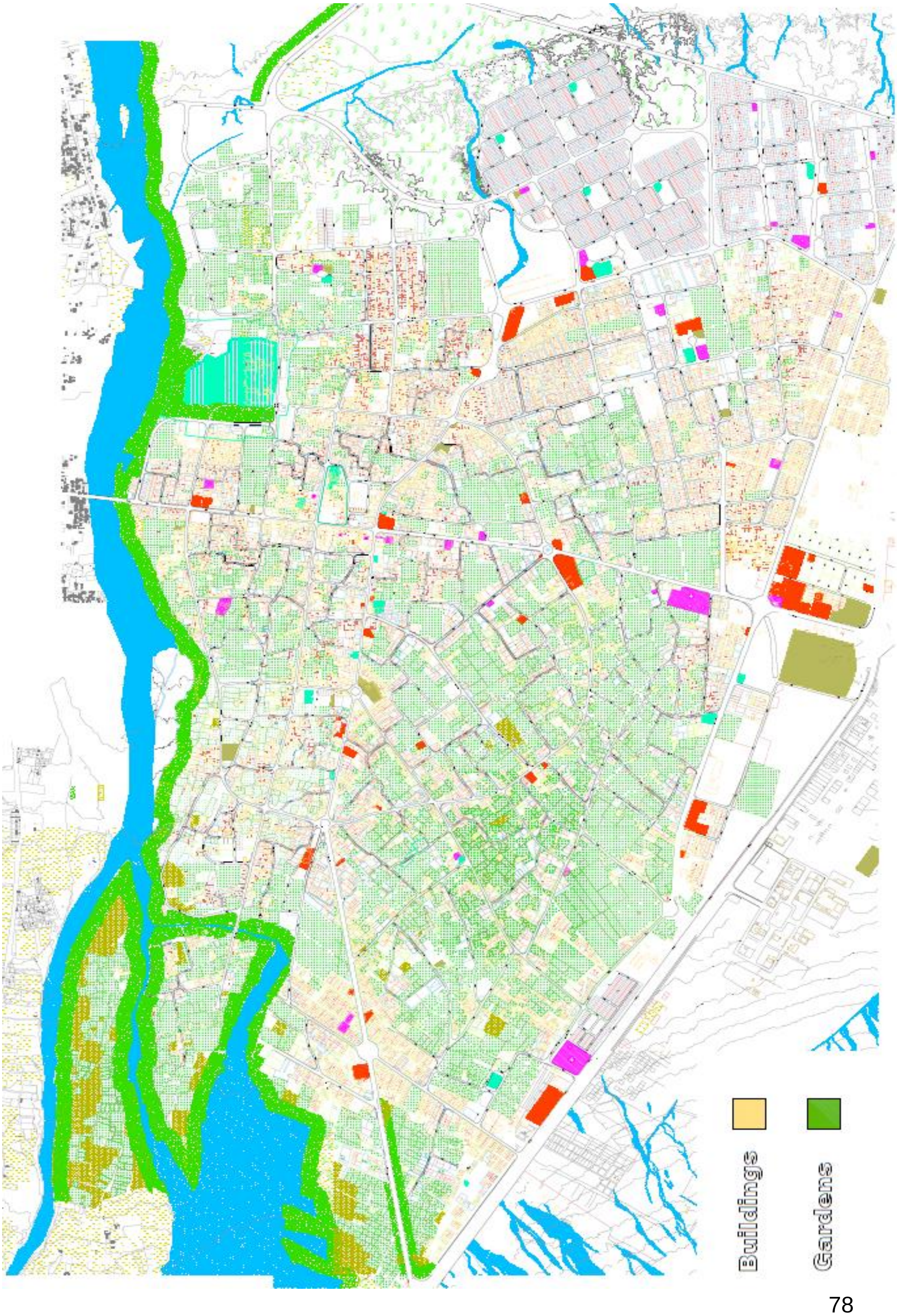
The third option was to live in open spaces between collapsed houses in their area such as parks or playground of schools. This option for temporary sheltering was a logical option according to their culture because people of an area generally know each other and mostly family or relatives would live in same camp. In this situation survivors have a chance to benefit from infrastructures and services of their area which are still useable after earthquake.

The fourth option was to live in their gardens and other open spaces close to their collapsed houses. This option is the most efficient option for survivors if infrastructures of the city or other services still work. Records shows that survivors in Bam were interested in this option for temporary sheltering (Fallahi, 2007).

Furthermore, records and statistics from research questionnaire that is attached in appendix 2, show that emergency shelters after moving to transitional shelter were used as a storage for survivors and transitional shelters, were used as a storage for survivors after moving to their permanent shelters in a corner of their gardens.

The strategy of temporary sheltering in Bam was a mixture of option three and four. Emergency NGOs through satellite images and existing maps identified lands, which had the potential to be sites for temporary sheltering. Through this strategy, survivors can live close to their collapsed houses in gardens. Furthermore, the structure of temporary sheltering would be in the same social structure as it was before because families and relatives still could live in the same area.

The biggest problem from satellite images showed that most of the city is covered by palm gardens, which does not allow for enough numbers of camps in Bam. Therefore, the local authority got permission to use their public spaces such as schools, sport fields. Finally, with all considerations 44 points in Bam were identified where the minimum land was 1,642 square metres and maximum land was 265,033 square metres for different purposes including temporary sheltering, field hospitals, educational (Abadi, 2004).

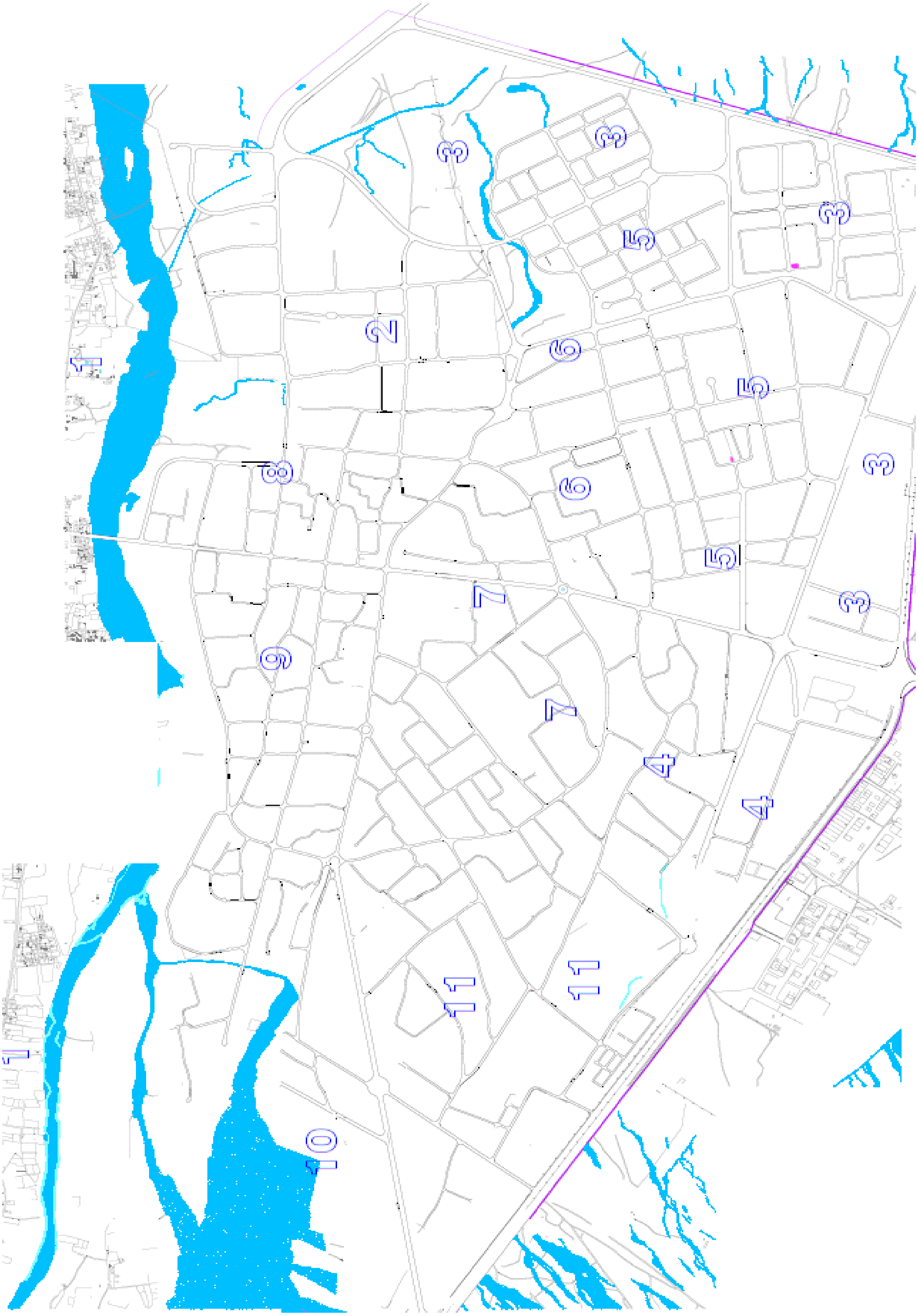

Buildings
Gardens

1.7.5 Statistics for economic and human losses in Bam

The local authority and NGOs predicted 17,000 units of temporary shelters for Bam; that is shaped from 5 zones and 22 districts. Through the urban and social structure of the city, 22 sites were selected for temporary sheltering where each camp on average should have a capacity of 773 units of temporary shelter. After deep consideration because of the different sizes of selected sites, 8 more sites were selected because some sites were too small for 773 units. The number of survivors in each camp was between 500 to 1,000 people (Fallahi, 2007).

To provide accurate statistics, fieldwork was needed. The local authority with the latest satellite picture and field works in each district of Bam confirmed that a range of damage was between 15% to 85% and there was no building in Bam that did not have any damages. On average the percentage of damages were 65.9%. The table below shows all damages according to different districts. (Abadi, 2004)

The city of Bam is 27 square kilometres and there are 18,000 residential and commercial buildings. Approximately 85% of these buildings collapsed. (Fayazi, 2011) Therefore, a big part of the city needed landscape recovery.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District	Population in 2002	Population density (per Hectare)	Area (Hectare)	Building damages (Percentage)	Death (Percentage)	Number of death	Calculation of damages
1	3350	54	61.48	92	9	2913	92
2	2567	40	63.84	65	2.39	772	32.5
3	2565	43	59.06	83.50	3.05	986	41.8
4	3752	41	91.04	88.60	4.89	1581	44.3
5	5317	34	155.54	88.60	7.03	2274	44.3
6	3655	11	334.13	70.6667	3.78	1222	35.3
7	3159	34	93.49	67.3333	3.10	1002	33.7
8	2362	33	70.96	65	2.18	705	32.5
9	4464	27	167.25	47.1429	3.12	1008	23.6
10	5566	10	549.63	15	1.24	402	7.5
11	3548	32	111.44	65	3.36	1086	32.5
12	6685	29	228.95	29	2.90	939	14.5
13	2883	15	191.05	17.50	0.72	232	8.8
14	5456	16	346.97	30	2.43	787	15.0
15	2541	27	95.24	75	2.70	875	37.5
16	5452	42	130.51	69.25	5.64	1824	34.6
17	6238	41	149.90	88.60	8.29	2684	44.3
18	4911	43	115.01	84.2857	6.16	1992	42.1
19	50.18	26	193.72	57.4286	4.29	1388	28.7
20	5611	30	190.16	53.50	4.45	1440	26.8
21	3892	29	135.50	92	10.39	3362	92.0
22	3369	11	305.97	92	8.90	2879	92
Total	92361	24	3840.84	-	-	32361	-

Table 1.6: *First statistics from damages and human loss (Abadi, 2004)*

1.7.6 Sheltering in earthquake response cycle

One of the important damages caused by earthquakes is collapsing houses and its effects on survivors in the short and long-term effects such as losing security, protection from climatic issues. All of these reasons make temporary sheltering very important in post-earthquake times. In this part, the process of sheltering is expanded upon to explain different types and approaches of emergency sheltering and transitional sheltering in an industrial focus and local focus. Each type of temporary sheltering is because of specific purposes and reasons in post-earthquake scenarios. In addition, they have their own limitations according to their site conditions. Different reasons such as economic or historical condition could be the reason of limitations in earthquake response cycle. In Bam, historical citadel caused many limitations in earthquake response cycle, expanded upon in Chapter Three, Bam field work. This part clarifies temporary sheltering approaches through explanation of some temporary sheltering approaches.

The disaster response cycle is an academic model, which explains the priorities and processes of responding (Pelling, 2003). Key stages in this cycle are identified. This part of the research is to recognize all of the stages of the cycle, which are close to each other or in some cases are linked to each other. The earthquake response cycle starts with relief, which consists of different steps including precautionary evacuations of threatened people, emergency rescue of trapped people and emergency sheltering.

At the beginning of the earthquake response cycle, several immediate actions and equipment are required. One of these immediate needs are medical responses. Therefore, immediate architectural need such as field hospitals and shelters for survivors would be required, which needs a quick response from the emergency NGOs. Efficient emergency sheltering in the earthquake response cycle affects preparation of first aid points and transportation of survivors and injured people to a field hospital.

Temporary sheltering consists of two steps in a post-earthquake scenario. Firstly, short-term temporary sheltering that can happen through tents. Secondly, long-term temporary sheltering that can happen through transitional shelter such as porta cabins. This research focused on short term temporary sheltering because long term temporary sheltering engages with cultural issues. In the other words, every geographical location needs its own long-term temporary shelters.

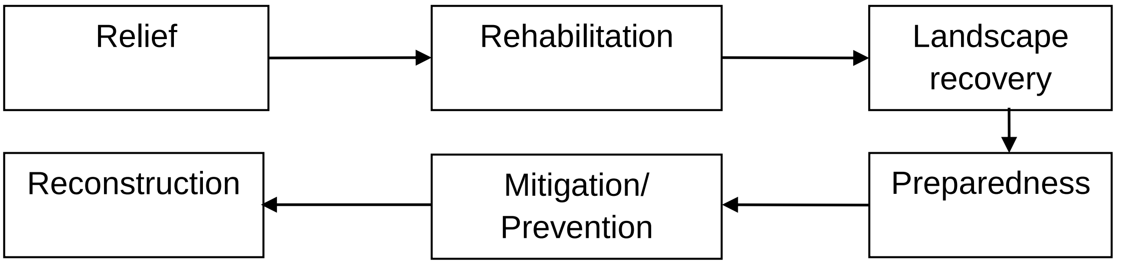

Diagram 1.9: *Existing disaster response cycle (Article 25 conference/ Nov 2010).*

1.7.7 Process of temporary sheltering

Throughout history, shelters have been one of most important items of people's life and nowadays it is a human right. In the Universal Declaration of Human Right and Article 25 conference it is clearly mentioned that "Adequate shelter and housing are a fundamental human right" (UDHR, 1948[18]; Morsink, 1999)

After the industrial revolution, specifically between 1900 and 1950, with the expansion of cities the development of infrastructure such as the emergency services were shaped, therefore quality of life improved and different factors such as health and safety improved (Health, 2000)[19]. However, health and safety issues in Iran during 1959 to 1979 became more important because it was at the same time of modernization and industrialization of Iran. Before the 1979 Iranian revolution, the health and safety was based on American rules and regulations. After this time new government was benefiting from infrastructures that the Shah of Iran founded. For instance, during the 8 years of war with Iraq, when Iraqi forces were bombing cities, different organizations such as fire departments, ambulances, Red Crescent, the army were responsible for responding to injured people. After the 8 years war, there was a reconstruction experience for different organizations which led to the improvement of national/ international building codes. In addition, after the 8 years war the situation became better and health and safety issues improved. For instance, National Building Codes provided in 1988 and latest version which is the 3rd edition of national building codes in Iran was released in 2005, has parts which emphasize the health and safety issues in permanent buildings (No, 2005).

As previously stated, different United Nations manifestos (Gostelow, 1999) and Human Rights charters (UDHR, 1984) mention that these developments are important. Finally, as numbers and statistics prove the increasing number of natural disasters and economy losses through history (chart 1.1, 1.2) equipment and strategies of sheltering (Diagram 1.9) are being upgraded in a few cases; these developments in emergency sheltering are expanded in Chapter Four.

> "By the nineteenth century, portable structures had grown in numbers as new settlement and colonies were formatted, and with them, a demand for immediate housing solution. Iron buildings shipped to British colonies later in the century are another. By the early part of the twentieth century, architects and inventors were experimenting with these systems for housing" (Arieff and Kaufmann, 2009:52)

The statement above shows that sheltering must develop as fast as human need. Generally, the shelter as a human right consists of temporary shelters and permanent shelters for different situations and conditions of human life. Different NGOs, because

[18] See appendix 2

[19] Iranian Government Printing Office

of emergency situations and facilitating relief stages, introduce emergency sheltering as an immediate architectural need (Winandy, 2006). Emergency shelters are the immediate needs for short-term sheltering and a temporary solution to provide long-term temporary shelters. Finally, longer-term temporary sheltering in post-earthquake scenarios provides time to reconstruct permanent shelters. In the disaster response cycle short term temporary shelters are called “Emergency shelter” and long term temporary shelters are called “Transitional shelter” (Bolin, 1994).

Emergency sheltering → Transitional sheltering → Permanent sheltering

Diagram 1.10: *Process of sheltering in a post-earthquake scenario.*

1.7.7.1 Emergency Sheltering: Emergency shelters are temporary places where survivors live for a short term until transitional shelters become provided for survivors. Emergency shelters even sometimes become more important because during relief and rehabilitation it is an immediate need. Emergency shelter in the disaster response cycle can be a key immediate need to save human life and prolong survival (Davis, 1978). There are some differences between emergency shelters, transitional shelters and permanent shelters. Generally an emergency shelter is a unique space that is multi usage e.g. for eating, sleeping, reading in the same space. It is a temporary shelter for daily activities. Typically, emergency shelters with existing equipment are tents and consist of a lightweight structure and tarpaulin, a lightweight fabric, to cover the structure.

> “When people lose their homes, they have lost the last place regarded as essentially safe. Therefore, when an individual is without shelter, the situation can be described as a crisis.” (Babister and Kelman, 2002:12).

Emergency shelters facilitate responding to immediate architectural needs in a post-earthquake scenario. In a post-disaster scenario often these kinds of shelters are provided by emergency organizations such as the Red Cross and Red Crescent, UNHCR or other emergency governmental or non-governmental organizations to facilitate relief during the response cycle. Depending on cultural expectation and funding, mostly NGOs use tents as emergency shelter equipment. In addition, as the figures 1.13 and 1.14 below show, in some cases public buildings such as schools, churches, sport centres can be used as crisis points to respond to the survivor’s immediate needs.

Figure 1.13: *Haiti as a poor country, predicted a crisis point for emergency sheltering, a school during the post-earthquake period.*

Figure 1.14: *A sports field as crisis point for emergency sheltering during the post-earthquake period in Japan (Architect, 2008).*

These immediate architectural needs in a post-earthquake scenario are firstly protection from the elements, secondly, preservation of dignity and finally orientation and identity (Babister and Kelman, 2002), provided by emergency sheltering.

Environmental protection is an important item, After Relief (Ref) survivors should be protected from environmental issues such as rain, snow and wind. For instance, during the Bam earthquake, with a hot and dry climate, survivors and food were protected in emergency shelters for a longer term. There were many advantages for survivors to live in emergency shelters rather than staying outdoors in the hot and dry climate. Furthermore, in a post-earthquake scenario, there are many aftershocks and it is not safe for survivors to be kept in permanent shelters.

In addition, these settlements can provide time to prepare the next step of the sheltering process. For example, in a post-earthquake scenario the role of an emergency shelter is to buy time to provide transitional shelter and at the same time to improve the living conditions and the role of a transitional shelter is to provide time and better living conditions to reconstruct permanent shelters. There are a lot of NGOs that provide these kinds of shelters for the earthquake sheltering process. Shelter Box, is one of the latest, providing equipment for emergency sheltering, and has worked for many emergency services and delivered globally. Shelter Box consists of a tent, a first aid box and other equipment for temporary living such as a cooker, blankets, water storage and purification equipment (de Magaz et al., 2005).

Figure 1.15: *Shelter Box with equipment inside*

Figure 1.16*: Shelter Box in post-earthquake time, Italy*

> “Only new equipment is used and is carefully selected for durability, practicality and suitability for where it is needed, tough, lightweight and waterproof, the box itself can also have many useful functions such as food container. We also continually work with a range of manufacturers to improve the quality and extend the range of equipment that we have available” (de Magaz et al, 2005:2).

The most important part of Shelter Box is a disaster relief tent. There are different sizes of emergency shelters but the maximum number that it covers is 10 people. It is designed for the worst conditions such as strong winds, high or low air temperatures and heavy rain or snowfall. Furthermore, inside of the tent, residents, because of some partitions, have good privacy. Shelter Boxes have been delivered to 35 countries including Iran, Italy and Haiti as developing, developed and poor countries for post-earthquake scenarios as emergency shelters.[20]

In Iran, there are different manufacturers in the whole country who manufacture different types of tent for different purposes. However, the Iranian Red Crescent buys different numbers of tents from these manufacturers, which are manufactured under specific standards; which are mentioned in section … (ref).

1.7.7.2 Transitional shelter

Generally, transitional shelter is the name of different types of temporary shelters that people live in for a short or long time until permanent shelters become reconstructed (Arieff and Burkhart, 2003). In the disaster response cycle, transitional sheltering as long term temporary sheltering is the second step of the sheltering process (Diagram 1.9) and transitional shelters help survivors displaced by an earthquake until their lives go back to normal in permanent shelters. The research developed emergency sheltering because emergency sheltering does not engage with cultural issues as it has a global strategy but transitional sheltering engages and it can be designed specifically for different areas and different uses. However, this section expands on

[20] Article 25 Conference , Manchester, Nov2010

transitional shelters and permanent shelters with differences. Transitional sheltering is a method of housing to maximize privacy in mid-term sheltering in the scenario during temporary sheltering. This type of transitional shelter reduces the costs of erection of the shelters in post-earthquake scenarios and provides security from the beginning of the long-term temporary sheltering in a post-earthquake scenario.

Transitional shelters, because of longer settlements, engage with cultural, economic and religious issues and do not have global strategy. The strategies could be local for different uses such as residential, official for more efficiency or it could be by local materials or recycled materials. However, because of its features, such as the ability to transfer, it is possible to manufacture it off site and transport it to other locations.

Transitional sheltering in the process of sheltering in post-earthquake scenarios could be different in countries with different economic levels. The cheapest option of transitional shelters, in the author's experience, is a porta cabin; this is a very simple box with 3 windows and a door. As the figures 1.17 and 1.18 show, it can be manufactured with different material such as metal, wood or paper tubes in a factory or on the site of earthquakes.

Figure 1.17: *Transitional shelter, manufacturing and assembling in factory Credit image: Alejandro Dumay (Arieff and Burkhart, 2003).*

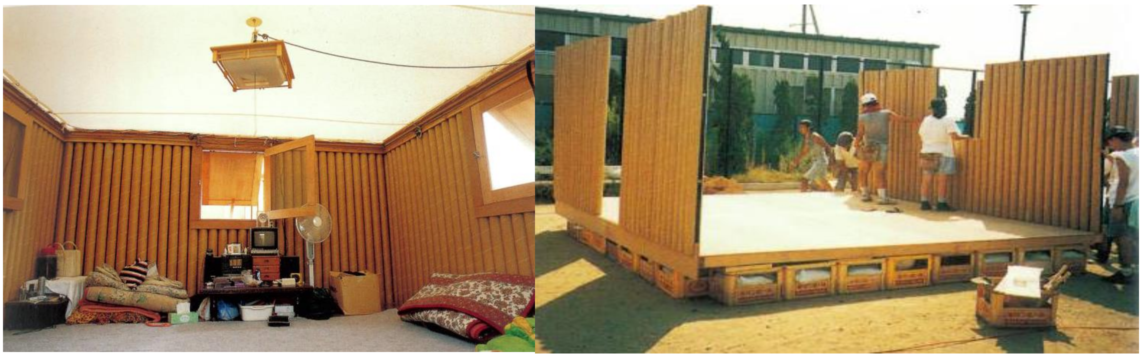

Figure 1.18: *Transitional shelter, manufactured offsite, assembling onsite in the post-earthquake scenario in Turkey (McQuaid, 2003)*

Finally, the transitional shelter is a type of shelter where survivors in a post-earthquake scenario usually live in families and groups. They live there for a longer term in comparison with emergency shelters in a post-earthquake scenario, until the third step of sheltering which is permanent sheltering, takes place. The length of stay, depending on the economic level of the country could be different in a post-earthquake scenario. In some cases, such as survivors of the Bam earthquake after nearly ten years they are still living in their transitional shelters. Transitional shelters ideally could be built from local materials for more sustainability in the short term and long-term use.

Sustainability in long-term temporary shelters is one of the issues that, in comparison with short-term temporary shelters, is more important.

There are different types of transitional shelters for different purposes and different climates such as transitional shelters for post disaster times, military transitional shelters or holiday caravans. All of these environmental and cultural factors will affect transitional shelters design such as form and material. Even the transitional shelter can be in the form of a vehicle such as caravan (Clutton, 1971).

Sustainability in long-term temporary shelters is one of the issues that, in comparison with short-term temporary shelters, is more important. In some cases, transitional shelters can be made from recyclable materials. Many of the transitional shelters feature the use of renewable and recyclable materials and energy sources. A common characteristic is how lightly these materials sit on the land, establishing a dialogue with the environment instead of an occupation (Arieff and Burkhart, 2003).

Figure 1.19: *A transitional shelter made from corrugated metal sheets* (Arieff and Burkhart, 2003)

The third step of sheltering is permanent sheltering. Permanent sheltering needs education, budget from government agencies and engages with cultural, climatic, religious and other issues in architecture through long term sheltering (Babister and Kelman, 2002). The process of permanent sheltering in developing, developed and poor countries are completely different. Permanent sheltering, similar to other types of sheltering, is for protection from the elements, preservation of dignity and finally orientation and identity. There are many low-tech and high-tech methods for permanent sheltering in different countries.

In Iran reconstruction of permanent shelters and providing temporary shelters are mostly the responsibility of governmental organizations. Therefore, collection of temporary shelters are possible to reuse in next earthquake. However, in developed countries mostly emergency sheltering, transitional sheltering and reconstruction of permanent shelters would be responsibilities of different NGOs. Therefore, mostly survivors would be the owner of the temporary shelters. However, after the Bam earthquake, the Ministry of Housing provided tents and porta cabins for survivors through the Iranian Red Crescent. They did not collect tents but they collected porta cabins in camps.

1.7.8 Sheltering with industrial focus

The history of manufacturing temporary shelters on an industrial and huge scale refers to the beginning of the twentieth century. For example, survivors in the Messina earthquake in 1908 experienced temporary shelters that were manufactured on a huge scale. At the beginning of the twentieth century, with agricultural and industrial developments, growth of prefabricated temporary shelters provided many possibilities for the building industry. In the figure 1.21 is an example of a prefabricated transitional shelter that farmers in Germany could buy, in four sections separately and then attach together next to their farm for a big unit transitional shelter.

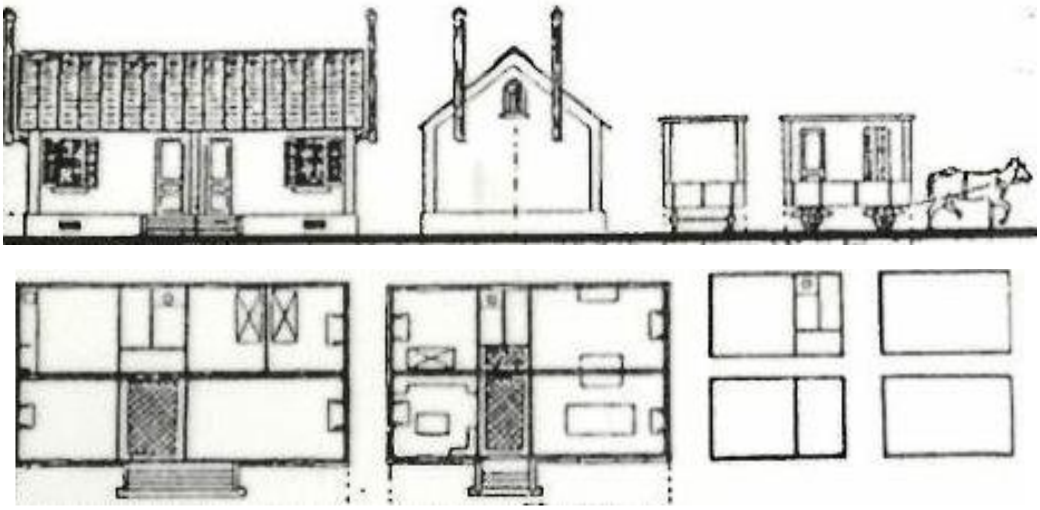

Figure 1.21: *An attachable transitional shelter in Germany (Abadi, 2004)*

The table below shows that earthquakes less than 2 on the Richter do not cause any damage and no one feels any tremor but for earthquakes more than 3 on the Richter emergency NGOs should respond urgently and the disaster response cycle should be applied. Medical rehabilitation is a priority in the earthquakes between 3 to 5 on the Richter. Experience and statistics from Table 1 show that earthquakes between 3-5 on the Richter scale cause the shaking of objects inside the shelters but it does not cause any damage to buildings. However, the buildings with poor structures start collapsing with earthquakes of five Richter or more. Therefore, emergency NGOs should respond to immediate architectural needs in post-earthquake scenarios with emergency shelters, field hospitals. This research has designed emergency shelters for earthquakes with scale 5 to 10. Chapter Four considers the disaster response cycle in earthquakes scale 3 to 10 and lessons learnt from previous experiences.

Richter scale	1	2	3	4	5	6	7	8	9	10	11	12
Requiremen			Medical care required		Emergency shelters						Not reported through history	
Results			Shaking indoor objects		Building damage							

Table 1.7: *Scale of the earthquakes and architectural responses.*

1.7.9 Erectable and foldable structures

During the 20th century, Buckminster Fuller was one of most important architects in terms of portable architecture and was influenced by the American car industry. He designed an erectable geodesic dome for deployable structures that utilised a scissor action (Fuller et al., 2008). For the first time, the American army applied his geodesic domes and confirmed that Fuller's domes were suitable for emergency shelters in the army; this application has been one of most important developments during last decade. In addition, the US army says that the geodesic dome is 75% lighter than a tent and 88% quicker to erect. Finally, the geodesic dome is stable against winds of up to 150 miles per hour (Faridni, 2006). Deployable structures remain easy to use, especially with modern technology including material and structure design. With these kinds of innovation, it will be possible to develop existing emergency shelters. However some developments have been done with deployable structures which will be consider one by one.

In contemporary architecture, the application of a new generation of deployable structures have been used since 1960. One of the most famous architects in the world, in terms of deployable architecture, who has followed Fuller's concept was the Spanish architect Emilio Perez Pinero (Pinero, 1976). He is known as the first person who applied deployable structures by utilizing scissor action in the history of deployable architecture. In 1961, he presented a model of mobile theatre in an IUA competition in London, which won the first prize. His model consists of some elements and modules with permanent connections while other elements of the model needed some hooks for more stability. His model could be expanded and cover a big space in an erected position, while in a folded position it was small. In addition, the geometry of the structure was very simple. Every element of the model was affected only by its weight, without any tension or pressure on elements (Robbin and Wrede, 1996).

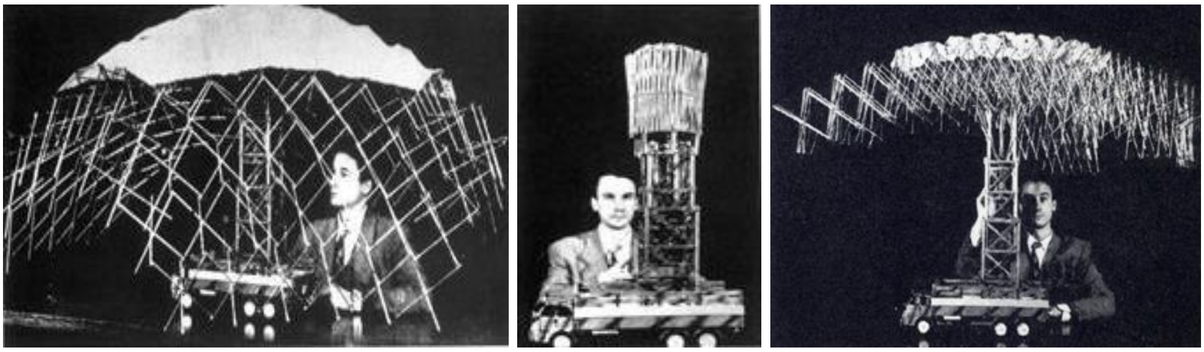

Figure 1.22: *Pinero in an IUA competition in London 1960. He is presenting his model as a mobile theatre (Sorguc et al., 2009).*

In that time, Pinero introduced deployable architecture as an interesting and flexible space and his model was registered as an iconic work in terms of deployable structures. Since then his work has become a basis of research for architects and engineers, such as Zeigler (Zeigler, 1977), Derus (Derus, 1984), Nodskov (Nodskov and Thelander, 1986), who have had some innovations with improvements of Pinero's work. For example, Felix Escring and Jean Perez Valcarcel from Spain have done some research on deployable structures utilizing scissor action and their team made improvements on Pinero's research from 1961. They could regenerate deployable structures with the application of structures utilising scissor action. Their team had some analysis, computer modelling and pantograph modules, which could work with plate elements. The other investigation of this team was the coverage of spaces with these structures as overlap plates or film (Faridni, 2006).

In the third international conference of space frames in 1974 participants had many ideas, most were similar to Pinero's concept but some of them had innovative suggestions in terms of connections, assembly and construction to make curves in one or two directions (Sokolowski and Tan, 2007).

In 1974, Theodore Zeigler, on discovering the weakness of Pinero's structures, presented his own innovation. His suggested that the structure consists of linear elements in a sphere shape. The major change of Zeigler's work was the stability of the structure without any extra objects. A few years later Y. Rosenfeld in Technion, with Pinero's concept and Felix Escring's concept, constructed a sphere with a radius of 2 metres that in a folded position had a size of (0.15× 0.3 ×1.8) metre. This structure had only 20 kilograms of weight and in 20 second was able to put into extended position by everyone without any technical skills (Faridni, 2006). Rozenfeld had a computer program for designing deployable structures. This program calculates the size of each element, objects and the location of them. The final shape of structure comes from analysed data such as number of objects and different parameters (Robbin and Wrede, 1996).

During the last decades with lots of developments from key designers, which was expanded on above, their main concepts have been the reason for the many creative designs from many architects in contemporary architecture to apply in their own design. This research implemented the output of the key designers of deployable structures after deep consideration with an engineering focus. Architects have used deployable structures in a different scale and building types such as permanent shelters, transitional shelters and emergency shelters. This research shows that there are few cases of emergency shelters, in contemporary architecture, which have implemented deployable structures. Those emergency shelters in deployable structures in reality are not efficient because of different reasons such as high-cost. Therefore, tents are still more efficient in comparison with new emergency shelters in contemporary architecture. However, in terms of function those emergency shelters have been efficient in terms of quick erection and space covering. The implementation of deployable structures in contemporary emergency sheltering which are relevant to this research are expanded on below.

1.7.10 Pre-fabricating emergency shelters:

With the migration of people to cities and the development of infrastructures in the cities throughout history, services of emergency NGOs have improved. With the industrial revolution, the application of some material such as concrete in housing was one of the important developments in different countries. Applications of steel frames, space frames and the innovative structures are the best examples of industrialization (Morris, 2013). Generally prefabricating shelter is the process of the sheltering away from the shelter site. The output of prefabricating shelter can be permanent shelter, transitional shelter or emergency shelter. Therefore, in prefabricating architecture, different parts of the shelter with different materials can be manufactured then it can be assembled on site.

Prefabricating was one of the solutions after the industrial revolution for quick and cheap shelter. Le Corbusier was one of these architects who developed new methods of housing by simplifying prefabricated shelters with mobile walls, roofs, windows and doors (Frampton, 2001). Alternatively, Walter Gropius has provided a lot of lessons in terms of prefabricating walls, partitions or other parts of housing in Bauhaus (Arieff and Burkhart, 2003). Finally, one of the most important people who has done a lot of innovation in terms of prefabricating specifically for mobile architecture was Buckminster Fuller (Fuller et al., 2008). He was one of most important humanitarian designers. In 1929 Fuller designed the “Dymaxion House” with a concept of “more with less” (Sinclair et al., 2006). The basis of his concept was efficiency of the house. For example, material efficiency is an important factor with cheaper, lighter, and less material use.

1.8 Material science:

This research, explored effective and creative methods and materials through prototyping in different wood, metal, foam workshops. Furthermore, this research focused on lightweight materials (Campbell, 2012) and smart materials (Maeda and

Suzuki, 2011; Ritter, 2007) to implement efficient material options (Fellows and Liu, 2009) in emergency sheltering with consideration of sustainability for short-term and mid-term.

There are many institutes and universities in the world such as University of Manchester, University of Cambridge and University of Tehran researching on material science and methods to develop material technology including lightweight materials. Scientists and engineers from these institutions regularly publish their research output in journals such as MRS bulletin from University of Cambridge or EMARAT Journal from University of Tehran. This research identify the latest technologies from different institutions such as digital fabrication in MIT (Seely, 2004). For instance, for strut deployable structure this research applied a laser cutter plotter or 3D printer for the joints of prototypes.

In addition, the world is facing contemporary environmental challenges such as global warming, climate change (Oberthür and Ott, 1999) and increasing natural disasters. This research considers a sustainable approach to be sustainable in the long term same as the world sustainable strategy.

Throughout time, people who lived in different environmental and geographical conditions have tried to adapt themselves with nature and local conditions. Generally, in different societies various reasons such as climatic conditions are the reason for different architectural styles. In other words, human adaptation to environment with focus on architecture leads to different architectural forms and sheltering materials. Selection of appropriate materials is a part of this adaptation to nature. For instance, survivors in the Bam earthquake covered their tents or porta cabins with palm leaves to cope with direct sun rays in summer time. Generally, local materials are more sustainable and efficient for housing.

In recent years with technological development, application of local raw materials in the building industry has been reduced. After the industrial revolution, to achieve more economical and environmental efficiency all industries tried to minimise their material use through the most efficient methods (Appleby, 2011) therefore, the study follows this approach in material selection to minimize raw material use and achieve more efficiency.

1.8.1 Lightweight Materials

Lightweight materials are a very important issue in science and engineering. As technology has developed, new lightweight materials and different creative methods have emerged. Material science concerning emergency sheltering is expanded in this thesis and suitable material options for emergency sheltering are introduced. In contemporary engineering, lightweight structures and lightweight methods are two important issues.

In general, lightweight materials and techniques are linked to make lightweight structures. For example, one of the methods for lightweight structural design is the use of hexagonal geometry in engineering while applied to an appropriate structure and possibilities.

With the development of engineering and manufacturing technology, the market for lightweight and compact materials has increased. During the last century some lightweight materials such as aluminium (Gourierfrery, 2004) and titanium (McQuillan, 1956), plastics (Engelsmann et al., 2010) and polymers (IUPAC, 2012) have been produced with technologies to be implemented in different industries.

Generally, different industries evaluate lightweight materials through four factors. These factors which include material selection, physical shape, function and efficiency are effective in lightweight materials (Judson et al., 2009).

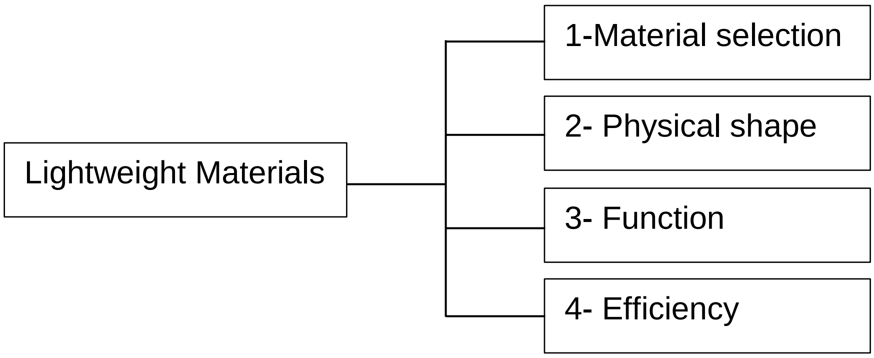

Diagram 1.11: *Process of assessment for selection of lightweight materials* (Judson et al., 2009).

There are a lot of engineering methods in the building industry to make shelter structures more efficient. For instance, one method of making lightweight structures is designing appropriate geometrical shapes such as the hexagonal geometrical pattern. This research applied a deployable geodesic dome, which benefits from this technique. More information is provided in Chapter Five as Structural Science.

There are a lot of differences between application of lightweight materials in other industries such as aerospace industry and emergency sheltering in the building industry. Different industries need different types of materials. For instance, in the aerospace industry materials should be light and strong while in emergency sheltering they should be low-cost and lightweight. Cost and weight are two important factors, however different industries are seeking their own priorities in material science (Campbell, 2012). This research for more efficiency of emergency shelters applies low-cost, light weight, environmental-friendly and sustainable material options.

1.8.2 Existing materials in emergency sheltering

Existing materials for immediate architectural needs consists of different types of petrochemical compositions and in some cases thin and low-cost compositions of aluminium to make lightweight shelters. During the second step of emergency sheltering, after unpacking and assembling the structure of emergency shelters, they should cover it with different materials such as waterproof cotton or tarpaulin. This area of emergency sheltering is one of the aims for this research to develop. These material options such as tarpaulin are designed for short term emergency sheltering and are durable for mid-term and long term temporary sheltering. Deformation of shelters or upgrading with readily available material by survivors is the result of applying these kinds of materials as survivors upgraded in Haiti 2 years after the earthquake (Figure 4.16). In addition, application of chemical material options or petrochemical material options in the long term cause environmental toxicity which this research developed this issue by application of bio-degradable material options.

These common materials in existing emergency shelters have different advantages and disadvantages from an architectural and engineering point of view. The most important advantage of the existing materials in emergency sheltering could be its availability and low cost which make it function properly worldwide. For instance, the price of a 10 metre roll of tarpaulin in shops in Bam is 480,500 Rials[21](16 USD). Disadvantages could be its toxicity in the long term, long-term degradability, and chemical processes for manufacturing. In addition, to fold and unfold, technical skills are required. Furthermore, existing materials for emergency sheltering are not durable and efficient for mid-term or long-term (Alloway and Ayres, 1997).

These factors affect the efficiency of the disaster response cycle and sustainability of emergency shelters. Therefore, with the environmental toxicity of the existing materials of emergency sheltering, which are mostly petro chemical materials, there is a gap in the global approach for sustainable development and sustainability of the existing emergency shelters. Environmental challenges and international agreements directly or indirectly confirm this issue (Oberthür and Ott, 1999).

Figure 1.22: *Tarpaulin as an existing water resistant material for coverage and Aluminium pole for structure*

[21] This research uses local currency in Iran because the currency exchange rate from Iranian Rials to GBP changes daily. Every GBP on average is 52,000 Iranian Rials.

1.8.3 Sustainable developments in material science

Sustainability in material science and developments in this field are at a global scale and this happens with collaboration of all societies, particularly in developed countries, where more energy and materials for manufacturing and further developments are required. Investigation in Chapter One shows that the scale of the collaborations to save the environment depends on management of material use, technological and sustainable developments and implementation of renewable energies. Generally, governments control this huge scale management (Apelian, 2012). Effective sustainable development needs an efficient infrastructure and good management. Sustainable development depend of three factors including society, economy and environment. There are different sustainable methods in material selection.

However Iran as a developing country, produces 1.7% of CO_2 emission in the world which is equal to 571512KT. Recently, with the growth of an educated population, research centres in Iran and international knowledge exchange between Iran and developed countries different techniques in different industries including building industry have been implemented to improve the CO_2 emission situation in Iran. Conducting different workshops for people, TV and radio advertisements aim to educate normal people to maximize the socioenvironment (Fallahi, 2008).

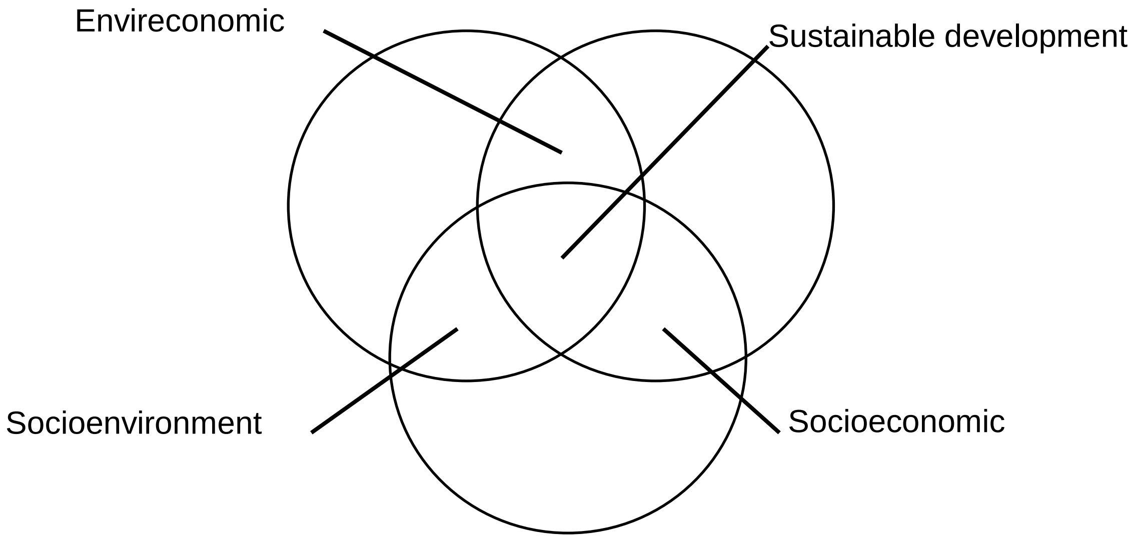

Diagram 1.12: *Sustainable development comes from intersection of three zones (Apelian, 2012)*

With the development of technology and the contemporary world approach to sustainability, future materials and methods of manufacturing should be sustainable. There are many restrictions in developed countries in terms of essential sustainable activities and guidelines on a national scale. Moreover, there are some agreements with the same approach on an international scale such as the Kyoto protocol. (Oberthur and Ott, 1999).

> “Future world will require materials that are fully recyclable or biodegradable, as well as a whole new paradigm for designing components by adopting a “cradle-to- cradle” philosophy that supports the remanufacturing of components from spent product into new products” (MRS, 2012:457)[22].

Parallel with environmental toxicity, material waste, energy consumption and sustainable developments, records and statistics prove that sustainable developments are not enough to cope with climate changes or global warming as contemporary environmental challenges (Oberthür and Ott, 1999).

> “Recycling is an integral part of any waste management system as it represents a key utilization alternative to reuse and energy recovery (waste to energy).” [23]

1.8.4 Methods of sustainable development in material science

Recycling materials is a very important issue to achieve sustainable development. The importance of recycling and repositioning is clearly understandable to avoid using raw materials and prevent damaging nature, global warming, or increasing the cost of raw materials gradually. In Bam survivors were reusing building materials from their collapsed houses to reconstruct their new permanent shelters. Therefore, with knowledge of the value of waste materials, recycling collection is important. These methods also have many advantages to save the environment, materials and money. Furthermore, the recycling of materials requires different technology. For example, different types of metals consist of different percentages of chemical materials, which might be inefficient or even cause environmental toxicity (Tsuchiya and Sumi, 1972).

This research has identified sustainable methods in diagram 1.2 and prioritises them for emergency sheltering according to the Bam situation. Generally, recycling technology affects the quality of the recycled materials. Recycled materials could be manufactured with different physical or chemical information. In some cases, the recycled item would be mixed with other polymers or chemicals to produce a new material with completely new technical properties. All of the recycling factories, chemical factories or natural resources in Bam, which can affect the material options in emergency sheltering, are identified. These sources of material for emergency sheltering in Bam are from the wood industry, chemical industry and paper industry.

Generally, everything on earth depending on their technical information is on the natural recycle system. Some such as glass bottles, or plastic products need a longer period to be degraded, for instance glass bottles take up to 1000 years to be bio-degraded and plastic products up to 400 years (Nash, 1995). This research, in Chapter Four, identifies short term bio-degradable material options as primary material options for short term temporary sheltering. In addition, it identifies long-term degradable

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[22] MRS April 2012. Materials for sustainable development. Materials Research Society, 37, P457.

[23] Recycling research and technology website, earth Engineering Centre, Colombia University

material options as secondary material options to upgrade shelters for long term temporary sheltering.

Iran, as an industrial country in the Middle East, produces and exports different types of building materials to Middle Eastern countries. These material options are from different industries such as the wood industry, metal industry, chemical and petrochemical material industry. However, this research focuses on readily available material options in Bam for prototyping emergency sheltering.

1.8.5 Wood Industry

Wood has been one of the most useful raw materials. Wood has been one of the building materials used through history in traditional and contemporary buildings in Iran. For instance, wooden beams are very popular in traditional buildings in Bam. As it is expanded on below, different types of wood product have been used throughout history in the building industry in Iran. Around the world, different types of wood are produced and there are many types of wood with different technical and physical information, which are imported to Iran for different purposes. There are different types of wood, which are very popular in the building industry in Iran because of their availability and low-cost, such as pine.

The different physical, chemical and mechanical features have made wood a unique material from an architectural view. In addition, with the development of technology in the wood industry, material science suggests different technological products such as engineered wood, which can be more efficient for different industries including the building industry. The availability of wood as a material option in the world is the biggest advantage for this research, which affects the simplicity of emergency sheltering. The second advantage of this material option can be its familiarity that affects the design of a self-construction emergency shelter in this research. Thirdly, wood is a biodegradable material, which leads to more sustainability in emergency sheltering. As the chart 1.3 shows, the biggest wood suppliers are located in different continents. Iran, in comparison with other countries in the world, is not a major exporter of wood in the world. However, Iran exports different types of wood products to different neighbour countries including 66% to Iraq, 18% Turkmenistan, 7% Tajikistan, 6% Afghanistan. Through different import and export statistics of wood products, Iran is the biggest importer of wood (Azizi, ghorbannezhad et al. 2009). This research expands on the available wood material options, which are available in Bam and have the potential to be applied to emergency sheltering.

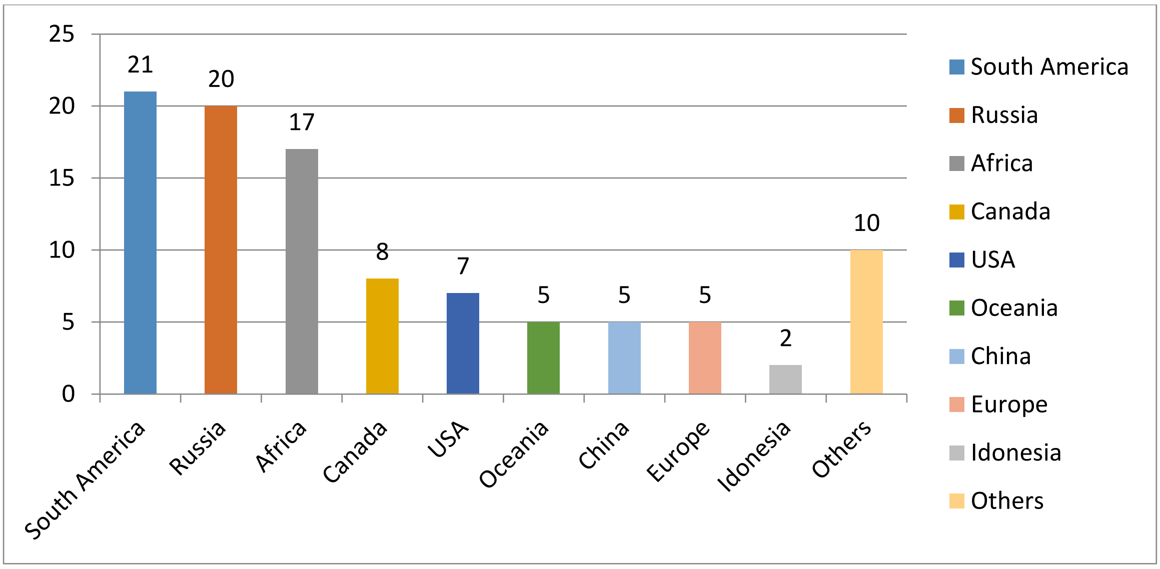

***Chart 1.3:** Market occupation of wood suppliers in the world, percentage (Katzenstein, 1985)*

Wood can be applied as strut in strut deployable structures and panels in surface deployable structures. However, wood in comparison with other material options such as water resistant cardboard causes more weight for emergency shelters. Moreover, wood because of its physical and technical properties has more potential to be implemented as strut rather than panels as it has been implemented as struts for prototyping because wooden panels would be heavy in comparison with other lightweight panels such as cardboard. In addition, this research applied a laser cutter plotter for cutting struts. Alternatively, there is some lightweight wood such as balsa wood, which costs more for emergency sheltering, in comparison to wood options that are proposed in Chapter Six. For example, a sheet of 5mm A0 corrugated cardboard 841x 1189 would be 69000 Iranian Rials (2.30 USD) in Bam but a package of balsa wood which has the overall size of 450mm x 100mm x 90mm a bundle would cost 780000 Rials[24] (26 USD). In addition, more waste cardboard is available in the world rather than waste balsa wood.

As the prices show because of the various types of wood, there are different prices and every type has different technical and physical information. This technical and physical data count as an advantage for this research. Technical data of wood can help the research to select the appropriate types, which are lightweight, low-cost, durable and available for prototyping in the workshop.

In addition, wood is an insulating material against heat and electricity, which holds advantage for emergency sheltering. However, the level of transference and insulation in wood depends on the percentage of water in its fibrous structure and its porosity

[24] This research uses local currency in Iran because the currency exchange rate from Iranian Rials to GBP changes daily. Every GBP on average is 52,000 Iranian Rials.

(Butterfield and Meylan, 1980). The research identified these types of wood for evaluation of their potential to be implemented in emergency sheltering.

All of the mentioned features of wood such as insulation, noise absorption and familiarity in Bam can be beneficial for emergency sheltering. However, these advantages should be compared with other material options in order to choose the best possible option for the project. Finally, the disadvantage of wood is the possibility of fire, which this research plans to upgrade emergency shelters through different methods including upgrading with fire resistant materials such as cement board, which because of the Kerman cement factory, it would be very low cost and efficient. In addition, there are different methods to make paper fire resistant, which are applicable in the wood industry too. An interview with Dr Philip Tougher at the University of Manchester (UMIST), Paper technology department shows that there are many methods in the field of material science which make paper and wood fire resistant.[25] The interview is attached in appendix 2 and methods to make wood or cardboard fire resistant is discussed in Chapter Six. Therefore, different methods improve the quality of emergency sheltering for this research to make water and fire resistant shelters in post-earthquake scenarios. These methods cover another item for material selection that has not been concerned in emergency sheltering before.

Generally traditional architects in Bam use a specific type of material in a specific part of the building pragmatically. For these experienced people, implementation of specific types of wood comes from their experience through long time working.

Wood products from the wood industry are divided into 2 groups including ordinary timbers and composite wood. Through normal timbers different formats of wood such as post, beams and planks can be produced which are very popular in traditional architecture in Bam. Engineered wood has different types of products such as fibres, veneers, boards or binding strands. In addition, other types of composites, which are readily available in Bam, are expanded on in Chapter Six, Material Design. For instance, wood base composites such as cement board because of the Kerman cement factory is a low-cost and efficient material option.

Some material options could be popular in the building industry in some countries. For instance, bamboo is a familiar and low-cost material option in Southern American countries which can be applied in the building industry while in other counties it is high cost and decorative such as Bam. On the other side, palm leaves are a very characteristic material option, low cost and popular material option in Persian Gulf countries.

Palm leaves: Palm leaf is a low cost, lightweight, sustainable and traditional material option which has a character in some countries. This part explains the application of this material in sheltering through history, and then consider its potential, advantages and disadvantages as a material for emergency sheltering. In addition, palm leaves, because of their low cost and lightweight are easy to transfer to other locations.

[25] Interview conducted in February 2013

As documents show, implementation of palm leaf in architecture goes back to seven thousand years ago. Documents from UNESCO show that in the North of the Persian Gulf, there is a historical site called “Chogha Zanbil” which has been registered as one of the human world heritage sites by the UN (Pingel, 2010). It is a historical holy city 45 km from Susa, Iran. Ancient Persian people were using palm leaves for roofing in permanent housing. It is an efficient material option in hot and dry climates in terms of stability against wind, sun and sand storms. Therefore, its sustainability, familiarity and degradability makes it a good material choice for longer-term emergency sheltering (Piesik, 2012).

Figure 1.26: *Chogha Zanbil, North of Persian Gulf.*

Figure 1.27: *Example of implementation of palm-leaf for roofing in abandoned houses.*

In addition, documents from the Centre of Persian Gulf Studies and archaeology in Sharjah[26] show the application of palm leaves refers to seven thousand years ago.

> “Remarkably, a house excavated at site 11 on Delma Island by Dr Mark Beech and Elizabeth Shepherd proves that the history of palm-leaf architecture goes back at least seven thousand years.” (Piesik, 2012:17).

The figures below show historical sites that have implemented palm leaf in architecture.

Figure 1.28: *Archaeology site in south of Persian Gulf in UAE and traditional palm leaf shelters* (Piesik, 2012).

[26] Located in United Arab Emirates

Figure 1.29: *Interior and exterior view of a palm leaf transitional shelter and implementation of palm leaf in roofing* (Piesik, 2012).

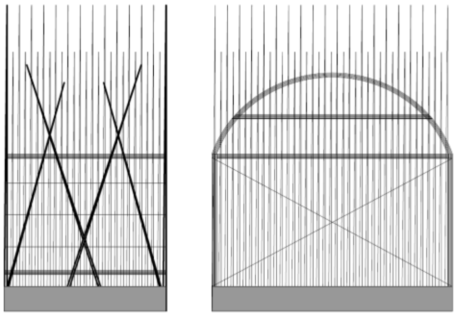

Figure 1.30: *Elevation of existing palm leaf shelters (By author)*

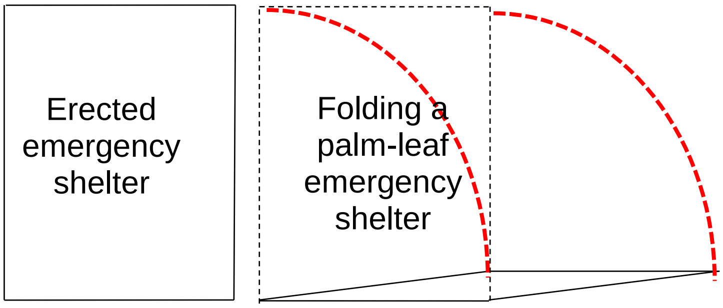

Figure 1.31: *Folding and erecting of palm leaf shelters as transitional shelters (By author)*

"Kapar" is name of a shelter type which exists in north of Persian Gulf including Bastak area in east of Kerman province and in west Hormozgan province. It is made of palm wood, palm leaves and in some cases mud. Local people and villagers during summer times construct a seasonal shelter in palm gardens to rest time to time during hot days when they have to work outdoor in their palm gardens specially during summer. They usually make 2 Kapar in their gardens. First Kapar for resting and second Kapar to keep drinking water tank and food.

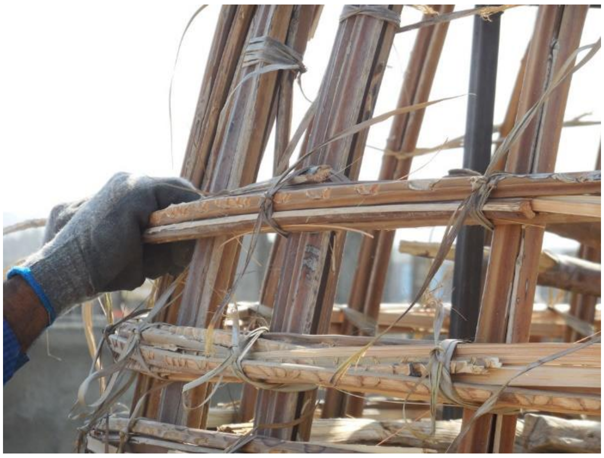

Figure : Palm wood and palm leaves are materials of a Kapar

(Ref: http://ghalehganj.com/en , Acess date: 14/02/2017)

Kapar is very low-cost shelter. Therefore, it is an ideal shelter for poor people to live permanently. They make a Sejam[27] by palm wood and palm leave to use inside the Kapar on the floor. Kapar is in dome shape which in local language it is called “toop” because this form is resistant against sand storms and strong winds. Lower level of toop should be closed because snakes and scorpions can go inside the Kapar if they find any hole in the body of the shelter. Therefore, they usually use mud.

Kapar as a local shelter has an iconic form in this area. Therefore, it is concept of different projects in contemporary art. For example, there is a touristic project in Kerman and Bam that used Kapar as a concept. For instance, Persian Qaleh Ganj Hotel[28] is the first Kapari hotel in the country. Booking and reservation records shows that it is one of favourite hotels for tours and travel agencies as it is a new experience for visitors and tourists to live in a Kapar. Below is images of Persian Qaleh Ganj Hotel out of Bam.

[27] Sejam is a bed made by palm wood and leaves to sleep on it. It has same construction method as Kapar.

[28] http://ghalehganj.com/en/

Figure: Kapar as a concept in tourism industry

(Ref: https://blog.safarme.com/adventure-and-tourism/ghale-ganj-kapari-traditional-hotel , Access date:14/02/2017)

1.8.6 Paper Industry

Throughout history, paper has been one of the oldest materials, discovered by the Chinese. Paper plays an important role in our lives because of its use for different purposes and because of the familiarity on a global scale. This research takes advantage of its popularity to apply it as a material option for sustainable emergency sheltering.

Paper is a traditional material and because of its flexibility in folding, easy cutting, marking, the low cost and easy degradability makes paper an important material for prototyping.

With the development of technology through time, different types of paper have been manufactured. Different paper thicknesses, water-resistant and fire resistant paper are the result of paper-technology development. Paper can be converted to different shapes such as paper tubes and cardboard.

Paper has much potential to be applied as a daily-use material. Advantages such as flexibility, popularity, and low cost have made paper an ideal material in in our daily life. Architects and students are using these materials for prototyping. Secondly, it is an important material in the engineering focus because of its potential to be converted to other materials with low cost. The paper tubes and paper sheets with various technical properties is the result of this development. As records show Shigeru Ban used paper in emergency sheltering for the first time and transitional sheltering in a post-earthquake scenario (Ban, 2006).

Paper Technology: Generally, wood can be converted to different products such as paper. The process of conversion plays an important role in paper technology. Paper consists of flattened interlocking plant fibres and for this reason, mostly cotton or wood can be used. Papermaking takes a long process that is in reduction of plant fibres, aligned with the adhesive, coating pigments and fillers including minerals. The process of papermaking is as follows:[29]

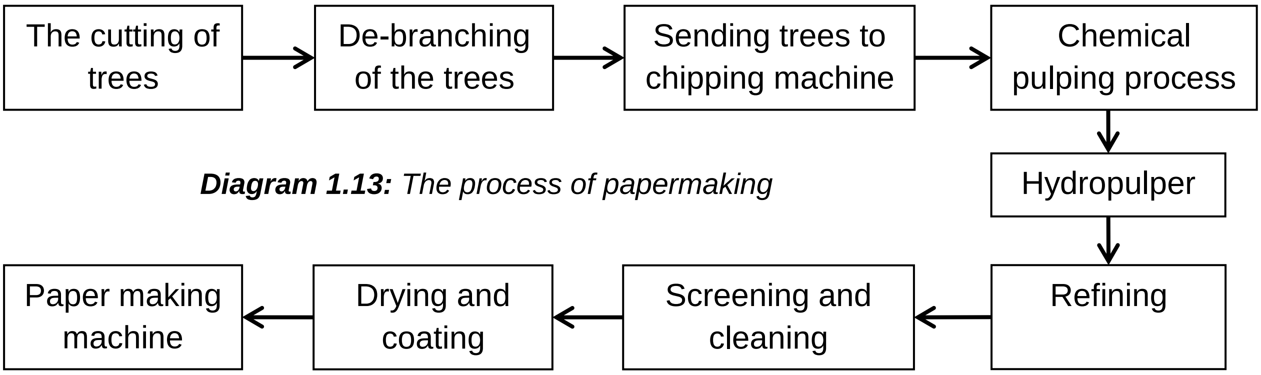

Diagram 1.13: *The process of papermaking*

The paper industry has many products with different technical and physical properties for different uses. These products depend on input materials and technology used for manufacturing would have different prices. Basically, in paper manufacturing providing raw materials as input materials has many negative environmental impacts and implementing raw materials is against the research approach in sustainability for emergency sheltering because it requires many trees. The statistics show that for 20-24 pound stock, which is roughly equal to 700 sheets of 17 by 22 inches paper, a pine tree should be cut down.[30]

This section provides paper-recycling statistics in three scales including world scale, Asian scale and Iranian scale to prove the potential of the paper industry in emergency sheltering. As European statistics show 81.3 percent of products in the paper industry have been recycled in Europe in comparison with recycling of products in other industries. The percentages in the glass industry are 70 percent and 74 percent in the steel industry.[31]

Different industrial statistics show the percentage of paper recycling out of various industries in Europe is higher and was about 81% in 2012. In addition, the aluminium-recycling percentage, which is a lightweight material for emergency sheltering, is 64%.

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[29] http://www.torraspapel.com/Conocimiento%20Tcnico/AboutPaperManufacturing.pdf accessed 25/02/2016

[30] ttp://www.torraspapel.com/Conocimiento%20Tcnico/AboutPaperManufacturing.pdfaccessed 25/02/2013

[31] European Recovered Paper Council (ERPC) Website accessed 28/09/2013

The recycling percentages of paper and aluminium can prove the potential of these materials as material options for emergency sheltering.

As a consequence, statistics show that the paper industry out of other industries has been more successful to join the world strategy in sustainability. Additionally, the percentage of paper recycling around the world has increased from 2%in 1991 to 6% in 2012. Therefore, it can be advantageous for this research. However, this research focuses on paper recycling in Bam to evaluate the potential of this material option for emergency sheltering.

Paper recycling statistic inside Europe are more developed and show the percentage rise from 23% in 1991 to 58% in 2012. Moreover, paper consumption is decreasing since 2005 inside EU. This percentage decreased from 82% to 79% in 2012.

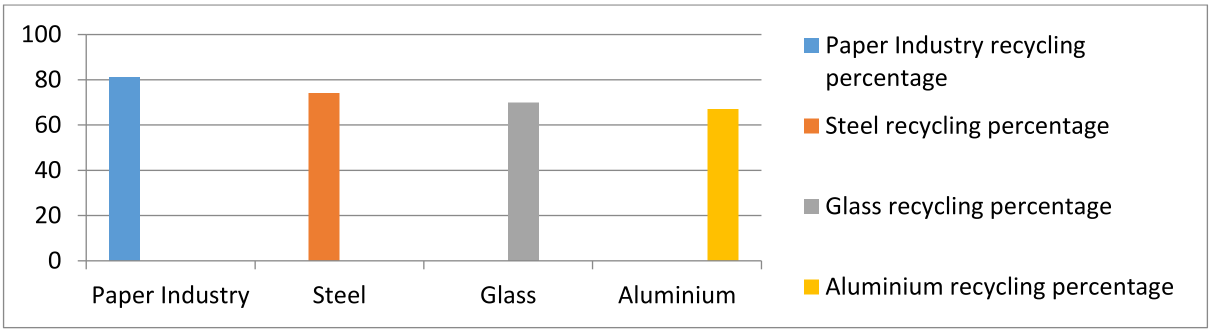


Chart 1.5: *Recycling percentage of main materials in Europe*
(Ref: http://www.paperforrecycling.eu Access date: 28/09/2013)

The table 1.9 below shows percentage of paper recycling in some Asian countries. This table shows that percentage of paper recycling in eastern Asia is higher than western Asia. Regarding to Bam earthquake it should be mentioned that paper recycling in Iran for 2003 is 11%. Recycling percentage constantly is increasing in Iran as a developing country. For instance, paper-recycling percentage in 2013 increased to 18%. These statistics and the increase in paper recycling show the potential of this material option in emergency sheltering in Iran.

Country	Paper recycling percentage
South Korea	66%
Indonesia	61%
Japan	61%
China	45%
Malesia	31%
India	30%
Turkey	26%

Iran	11%
Afghanistan	0.5%

Table 1.9: *Percentage of paper recycling in Asian countries in 2003 (Ref: Iranian Association of Paper and Cellulose Products, Access date: 01/06/2015)*

This research started providing statistics from world scale and finally focused on statistics of Bam. This research in section 6.8.1 identified paper-recycling factories around Bam with daily recycling statistics. In addition, it compares paper recycling statistics 6 years before earthquake to evaluate the capacity of paper recycling for emergency sheltering.

These statistics on a world scale show that the percentage of paper recycling is increasing as well as in Iran and particularly Kerman. It demonstrates the potential of this material option for emergency sheltering. In Chapter Six, this research focuses on the output of these statistics from paper recycling for emergency sheltering. There are different types of cardboard that this research applied for emergency sheltering.

1.9 Chapter Conclusion

The Literature Review in this research presented collected data through highlighting the gaps in emergency sheltering and in appropriate chapters discuss how these gaps can be addressed into the current position of emergency sheltering.

Firstly, this research distributed discussion around a sustainable approach to the discussion of emergency sheltering through different methods such as sustainable material selection approaches for long/ short-term emergency sheltering. Material options for short term emergency sheltering is named as primary material options, which should cover different items. These items are mentioned in Chapter Six such as low cost, lightweight, environment friendly while secondary material options should be readily available locally for upgrading for cold or hot climates. Volume B of this research provided technical details and material matrix.

Secondly creative deployable structure design is another development in this research to develop emergency sheltering. This development lead to self-construction emergency shelters, more sustainability and saving time, energy, transportation, and training volunteers.

Thirdly, Literature Review showed emergency NGOs design and deliver single units of tents in different sizes for different purposes. However, in some cases when they need large size tents and it is not available, they have to erect different number of smaller size of tents next to each other while this research respond to this gap through modular design of emergency shelters. For instance, rather than huge scale tents emergency NGOs would be able to attach different units of tent for different purposes.

In addition, the implementation of infinite energy resources develops emergency sheltering because it improves independent temporary shelters when there is not possibility to provide power for heating and lighting. For instance, role of solar panels, which have potential to be implemented in post-earthquake scenarios.

These socio-economic aims are concerned with environmental issues. In addition, this research into the disaster response cycle improved short-term sheltering closer to mid-term sheltering which is expanded completely upon in the Chapter Four.

Emergency sheltering as a short-term temporary settlement in post-earthquake scenarios needs development and needs to be concerned deeply in terms of sustainable design. Modular design in emergency sheltering for the first time with long-term environmental sustainability and global sustainable approaches are aims for this research, which have not been concerned before.

This chapter has explored different issues related to temporary sheltering in a post-earthquake scenario to support discussion in different chapters to develop emergency sheltering in Bam and the gaps. Below is a summary of the outcomes of the studies.

Strategies in sheltering	1- Short-term 2- Mid-term 3- Long-term

Conceptualising temporary sheltering and approaches	1- Concern about temporary sheltering as a process 2- Different approaches of temporary sheltering in a post-earthquake scenario - Settlement of survivors close to their collapsed buildings - Settlement in indoor/ outdoor public spaces. - Settlement in camps

Categorizing temporary sheltering in a post-earthquake scenario	1- According to the UN approach: emergency sheltering, transitional sheltering are stages of temporary sheltering through different equipment such as tents, porta cabins, prefabricated houses, and other types of emergency and transitional shelters. (see section 1.7.7.1 and 1.7.7.2) 2- According to the Corsellis (Corsellis et al., 2008) approach: survivors can be

	transferred to a permanent shelter of a family, friends or relatives. Alternatively, survivors can be transferred to a public building such as multi-usage sport fields, churches and schools. 3- According to Dr Fallahi’s approach: survivors firstly can live in camp as a group. Secondly, can live in individual tents in different places and finally a mixture of both. It means they can live as small groups close together and close to their collapsed buildings (Fallahi, 2008). 4- According to the World Bank’s approach: Survivors can move to stay with family, friends, and relatives, alternatively they can live in crisis points such as public buildings. Settlement of those survivors who do not wish to leave can be in their private lands. (Jha and Duyne, 2010).

Temporary sheltering	1- Main approaches for temporary sheltering are design approach, material approach and survivors approach 2- Process of temporary sheltering Emergency sheltering: Normal tent and cold climate tents. Transitional sheltering: porta cabins, prefabricated containers made by wood, concrete, or recycled materials. Lightweight temporary shelters made by local people using wood and leaves such as palm leaf. 3- International responses for individual temporary sheltering 4- International responses for group temporary sheltering 5- Planning methods for temporary sheltering: linear pattern, plain pattern and circular pattern

Planning for temporary sheltering	1- Key factors in temporary sheltering: protection, security, access, environmental concerns, cultural and social condition of survivors. 2- Temporary sheltering issues: Typology of temporary shelters, local conditions, climatic condition, long-term effects of temporary sheltering, budget, timing for sheltering, strategy for permanent sheltering and timing for permanent sheltering.

Location of temporary sheltering	1- Factors for locating a temporary shelter: access to water resources, population of survivors, access to site, neighbourhood, security, topography, green spaces, energy resources, cultural and traditional conditions, waste management, health and safety. 2- Methods of location finding: - Techniques of urban design: identification of empty lands with potential of being a camp, defining aims and objectives in planning, analysis and evaluating of sites for site selection and development. - Location finding for temporary sheltering with GIS and analysis of geographical condition through time (Kennedy, 2006).

This research through fieldwork in Iran and post-earthquake temporary sheltering, shows that emergency NGOs and designers, because of the temporary approach for these type of shelters in a post-earthquake scenario, focus more on final cost rather than concerning more on the quality of lives during temporary sheltering. Therefore, cost is the priority and an important factor in design. However, there are different types of improved emergency shelters that are expanded on this thesis such as Global Village (Figure 5.16), Ha-ori (Figure 5.20), concrete canvas (Figure 5.26). Certain minimum standards were identified which were applied.

Also the Literature Review identified some gaps in post-earthquake temporary sheltering which play important role in development of emergency sheltering. Some of the gaps such as application of sustainable materials in emergency sheltering, application of environmental-friendly materials and self-construction emergency shelters by survivors are some of the identified gaps, which this research is discussed in different chapters. Chapter Two expands on the research methodology of this practical research. It sets out the research agenda and the different methods, which this research undertake. This research applies a research methodology to respond to mentioned identified gaps.

Chapter 2

Research methodology

2.1 Introduction

The previous chapter explained the literature that has influenced this research. It identified the gaps through different lessons from previous experiences and investigation between actions after and before earthquakes. These gaps are going to be addressed through designing self-construction emergency shelters, extendable emergency shelter through modular design, and sustainable emergency shelter through short-term sustainability and upgradable for long-term sustainability.

The methodology undertaken in this research was designed as way to respond to the gaps found in the literature. This chapter sets out the research agenda and the different methods, which this research undertakes.

Different research methods were applied for different stages of this research such as data collection from different articles and library resources. Also research methods from other researches related to earthquake relief has been considered. The methodology in this practice-led research is divided into parts. The first part focuses on the identification of different methods for theoretical part of the research such as methods of data collection. The next part focuses on the identification of different methods for practical part of the research such as methods of prototyping (ref). All of these research methods support and gives structure to different chapters of this thesis to develop emergency sheltering. Development happens through responding to the identified gaps in the Literature Review. This chapter outlines in detail each stage of the research methodology.

2.2 Research methodology for this thesis

This research applies qualitative and quantitative research methods to structure activities for different stages of research and it gives separate reports for the theoretical and practical parts of the research. Different methods of data collection from multiple resources are recommended by Yin (1994). The research started from gathering information in the disaster response cycle and data collection from multiple resources such as libraries, e-books, interviews, magazines, newspapers, articles for different areas of emergency sheltering and existing equipment/strategies such as (Beaudet, 1999; Bolin and Stanford, 1991).

This research concerns the period of the disaster response cycle and its special conditions, which happen just a few hours after an earthquake. Earthquakes are unpredictable; therefore, data for emergency sheltering in camps or close to survivor’s collapsed houses, have been collected in post-earthquake times. In addition, data collection for the existing situation of emergency sheltering is important and fieldwork interviews with engaged people were planned in person or by social media. Furthermore, interviews were undertaken with people involved in the Bam earthquake for which national and international responses were required. It was necessary to ask for memories of interviewees to get in depth data collection.

Secondly, existing knowledge and case studies related to erectable, foldable structures (Guest, 2000; Gorman, 2005; Gantes and Konitopoulou, 2004) were collected and prototyped through different workshops to understand possible shelter designs undertaken in wood, metal, foam, digital fabrication laboratory. and experimented to develop models. This stage has its own prototyping process which were consists of sketching, digital modelling, small scale modelling, and large scale modelling. There are different aims behind each step.

A number of prototypes were produced (see Volume B) (ref) and tested by 3 groups of users to evaluate their efficiency as self-construction emergency shelters. Out of different structural designs optimum choices were selected. The taxonomy sheet in portfolio page 11 illustrates all of the design options. Finally, after testing and analysing different choices further developments happened in different aspects such as upgrading with secondary materials, lighting and other issues in emergency sheltering which are expanded in Chapter Five and Six.

This practical research uses a methodology cycle. The cycle of methodology consists of four key steps. The diagram 2.1 shows the cycle of the research methodology. The cycle of the methodology starts firstly with a plan, secondly through action, thirdly through feedback and finally through development. There are different qualitative and quantitative research methods designed for each step. These are expanded upon below.

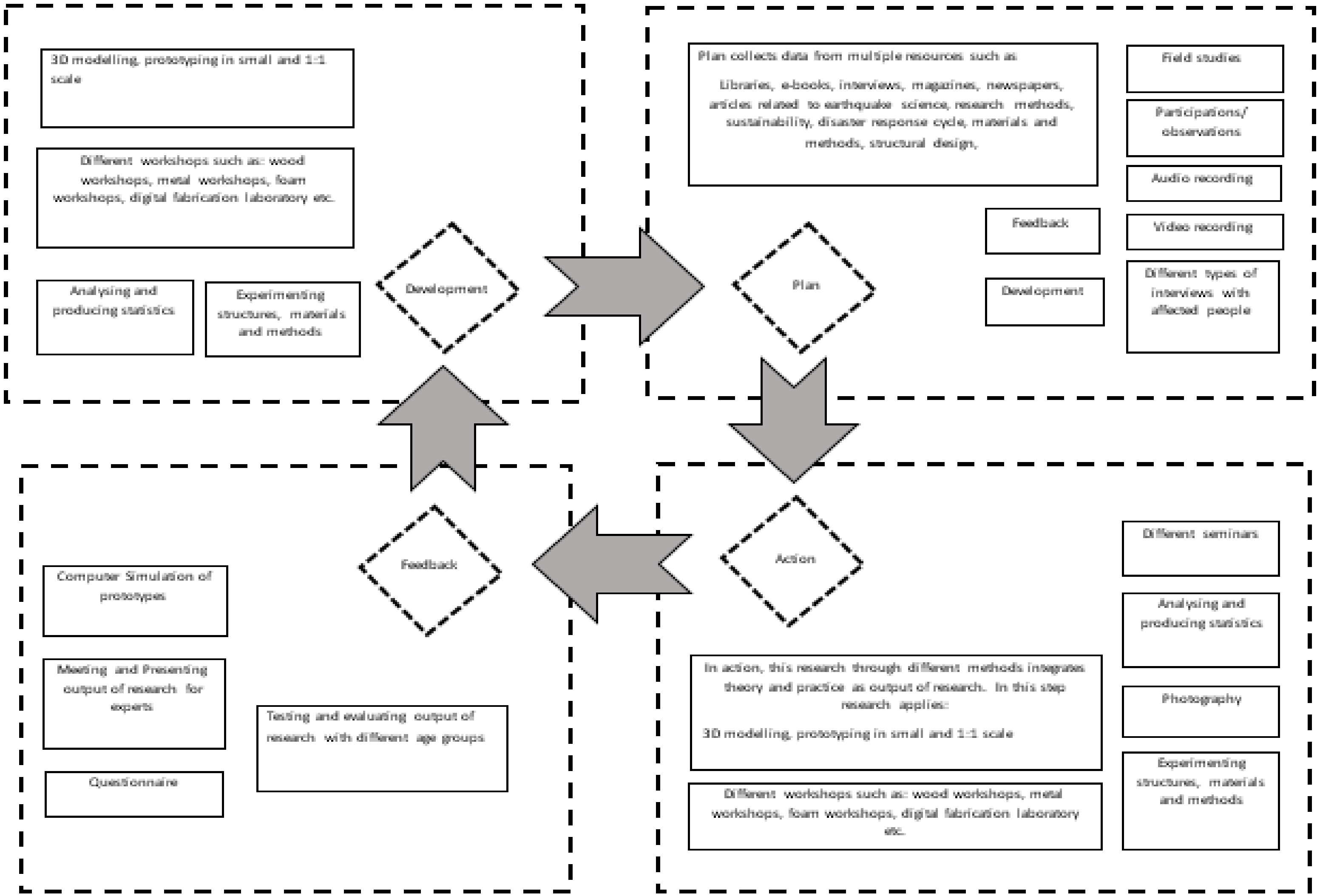


Diagram 1.10: *Methodology cycle of research (research by Practice).*

2.2.1 Plan (See Diagram 2.1): In the first step of research methodology cycle, data collected from different methods such as interviews, questioning, attending in conferences and conducting seminars and workshops. Below is the report of these research methods

The Literature Review collected a number of key references with, reading and investigating in books, articles and other library resources that are related to this research. There are a lot of references such as “Architectural planning for temporary sheltering” (Fallahi, 2007) or “Architectural responses to humanitarian crisis” (Sinclair, 2006), which are close to this research. Their research methods covers different areas in a post-earthquake scenario but this research focused and applied research methods related to emergency sheltering. In addition, personal experience of the author in the Bam earthquake as a volunteer and considering international references such as the World Bank reports (Jha and Duyne, 2010), OCHA instructions and Davis rules (Davis, 1978) led to efficient data collection in emergency sheltering that are expanded upon below.

The author started firstly, with collecting data from other post-earthquake scenarios in different countries (internationally) such as Haiti, Chile, Pakistan. The collected data from temporary sheltering which comes from different countries were summarized and only those outputs, which were related to this research, were used. Secondly, data from Iranian post-earthquake scenes were collected such as Tabas earthquakes, Roodbar earthquake. Finally, Bam fieldwork provided an appropriate reference in Literature Review. Therefore, the Literature Review structure consists of two sections including, global data and data from Iran.

Access to multiple resources: Access to multiple resources was the most important source of data collection in this research. Investigations into different issues related to sustainable temporary shelters in post-earthquake scenarios sourced from library resources. Issues such as the nature of earthquakes and structural research were designed from multiple resources. In this field the experiences of many academic institutions such as DSL[32] or MIT[33], many workshops such as “The Art of Engineering”[34] workshop, and research leaders such as Dr Chris Gantes (Gantes and Konitopoulou, 2004) or Simon Guest from University of Cambridge (Guest, 2000) and available PhD theses (Zhai, 2008 and De Temmerman, 2007) have been studied. Access to audio and video archives, such as BBC Persian for Bam and other earthquakes with effects on people were employed to document different steps of earthquake response cycle in this research. Digital recordings during interviews, photography during fieldworks, photography from research prototypes and existing equipment of temporary sheltering through the Red Cross are planned for the first

[32] Deployable Structure Laboratory (DSL) in the University of Cambridge.

[33] Massachusetts Institute of Technology.

[34] In Beheshti University, School of Architecture, Iran.

step. These images supports discussions in different sections of this thesis in both volume A and B.

After data collection, two different tables were designed. In the first table the author listed different issues discussed in each book and article. Outputs, gathered from data collection were extracted and listed separately as a table. Each table is explained in the Literature Review.

Interviews: Two types of interview have been planned for this research. Firstly, "The questions have been formulated ahead of time, and the respondent is expected to answer in terms of the interviewer's framework and definition of the problem" (Bryman, 1984: 77). In this type of interview, the author could compare different answers about the same issue. For example, this type of interview for data collection was useful to produce statistics through survivors in a post-earthquake scenario because all the questions were the same. The questionnaire is attached to an appendix that provided statistics during the Bam field work.

The second type of interview is the unstructured interview (Bryman, 1984:78) that allows more flexibility to gather information from survivors in a post-earthquake scenario. The unstructured interview is a method for getting details from experienced NGOs and survivors to help focus on different issues in the disaster response cycle. There might be specific questions from interviewees according to his/her situation and experience. This type of interview is not good for providing statistics in charts, graphs and percentages as an output. In addition, the personal experience of the author plays an important role in this part of the research and provides valuable context.

During a field trip to Iran, the author interviewed Dr Alireza Fallahi (see section 1.6.8) ref who is an expert in disaster relief and post-earthquake reconstruction, Miss Tara Jalali who is a MA Graduate from Beheshti University (National University), School of Architecture and NGO leaders such as Stephanie Jahnston.

Questionnaire: As expanded in the Literature Review, different assumptions and questions have been raised from different approaches and situations of temporary sheltering. Each question was considered many times and in different scales. Questions targeted mostly families as a basis of society[35]. In fact, the main aim of this thesis is to contribute to knowledge by designing different ranges of self-construction emergency shelters through engaging survivors with emergency sheltering. Therefore, responding to different situation of survivors is vitally important. Finally, questions were engineered to focus on a specific period that is a few hours after earthquakes for identifying immediate needs of survivors and to develop emergency sheltering.

This research considered the different methods of experts who have done research in post-earthquake locations related to technical issues, social issues or temporary sheltering. For instance, this included research methods designed for the development

[35] Number of temporary sheltering during Bam earthquake was based on number of families. For instance emergency NGO gave a tent to each family rather than each person or delivered specific number of porta cabin to each village or city according to number of families.

of technical issues of temporary sheltering during post-earthquake times (Fallahi, 2008); disaster response strategies (Johnson, 2002) researches with specific research methods focus on social issues in post-earthquake scenario (Fayazi, 2011). This thesis applies similar methods for different aspects of temporary sheltering. For example, this research related to social issues in emergency sheltering, interviewed and documented secure and unsecure situations, and the level of dependency in post-earthquake times. (See Chapter Three)

Research from the questioning of survivors had difficulty because, 14 years after Bam earthquake, all of the camps for temporary sheltering were removed and those sites changed to parks, buildings and sport fields. In addition, no one lives in emergency shelters in their private lands anymore and most of the transitional shelters have been removed from survivor's private lands or people are using them for storage. Therefore, the author through Dr Fallahi who has been one of the Bam reconstruction leaders after earthquake from central government and MA leader in Beheshti University was introduced and connected to 20 earthquake survivors from the Bam earthquake. This connection was through a virtual network and a chat room called Viber; a very popular social network between Iranians. Some of these survivors had been living in different camps and some of them in their gardens close to their collapsed houses. The author selected people from different ages, genders, occupations and educational level for a comprehensive result. At this stage, quality was more important than quantity.

On the first day of questioning Bam survivors, the author changed and developed some of the questions because of different situations of survivors in reality. All outputs of questionnaires shaped different charts and statistics that are provided in Chapter Three as the output of the Bam fieldwork. For example, each question from all of the interviewees informs percentage or chart or are categorized according to temporary shelter types. Finally, with relation to the research questions each chart or statistic contributes to the development of a different part of the discussion.

Producing statistics from designed questionnaires helped this research to answer some of the research questions. For instance, because of different life style in Bam it was realised that there are two groups of survivors. The two groups are; those who stayed in camps and those who stayed in their private lands such as their palm gardens. Answers from expert people who were leading Bam earthquake and survivors were also analysed. Finally, different data and figures from newspapers and different news websites completed the data collection.

The questionnaire, which is attached in the appendix was designed through a process explained in table 2.1. First of all the author identified references which focused on temporary sheltering. Those references were responding to specific problem or a question to develop. It helped this research to identify important issues in temporary sheltering. Therefore, different issues related to temporary sheltering in a post-earthquake scenario were listed. In the third column, different problems concerning temporary sheltering were extracted from different earthquakes around the world. These keywords are mentioned as items of temporary sheltering such as security, speed of erection, public services, and neighbourhood. The fifth column demonstrates the question types related to temporary sheltering. Finally, the last two column explains questions and the target of the questions. This method of questioning can help to provide statistics from survivors who experienced the same earthquake response cycle. (Change the table and columns)(Ref)

All of these items comes from effective items for temporary sheltering.

Reference	Reason	Temporary sheltering Items	Causes	Question type	Questions	Ask from
	Local people because of bad services and slow reconstruction left their city to live in other cities forever.	Location of living	Immigration/moving to other locations	Where?	1- Where were you living before Bam earthquake?	Family
					2- Where were you living during earthquake?	Family
					3- Where do you live now?	Family
	During temporary sheltering survivors with big families did not have a chance to stay in same temporary shelters	Type of temporary shelter	Suitability and flexibility	What type?	4&5- What types of emergency/transitional shelter did you use?	Family
				How many people?	6- How many people were in your emergency shelter?	Family
	Survivors after transferring to transitional shelter used their emergency shelter as store to keep their properties	Length and number of uses	Multi-time use of temporary shelters	How long?	7&8- Did you reuse your emergency shelter? if yes, what was the propose?	Family
					9&10- Did you reuse your transitional shelter? if yes, what was the propose?	Family
Iran, Roudbar (Fallahi, 2008)	Because of locating temporary shelters in survivor's land, they collaborated to construction to save time and cost	Survivors collaboration	working	How many days	11&12- Did you engage with emergency/ transitional sheltering	Family
				How many hours/ day	13- How many hours did you spend for emergency sheltering?	Family
Iran, Bam (Fallahi, 2008)	Survivors in camps because of robbing, raping etc. don't feel secure and are not satisfied.	Security	Feeling unsecure and dangerous situation	How long	14- How long did you live in temporary sheltering?	Family
				How many times	15- How many times did you feel unsecure and danger?	Family
Disaster Prevention and Management: An International Journal (Quarantelli 1995)	People because of living with their family members who were in their neighbourhood were more satisfied in comparison with people in camps	Neighbourhood	Number of family members	How many	16- How many of your family members were in your neighbourhood during temporary sheltering?	Family
			Number of familiar people		16- How many familiar people were in your neighbourhood during temporary sheltering?	Family
Macedonia, Skopje earthquake 1963	People who lived far from camps were more satisfied in comparison with people in camps because of bad public services such toilets and bath	Number of people who use toilets, baths	Using toilets	How many people	17- How many people were using toilets during temporary sheltering?	Family
					17- How long did you usually wait for toilets?	Family
			Using baths	How long	18- How many people were using bath during temporary sheltering?	Family
					18-How long did you wait usually for showers?	Family

Turkey, Duzce, earthquake (Johnson 2002)	Because of delay in temporary sheltering, survivors started sheltering by their own.	Speed	Time for sheltering	Beginning	19-When did you start temporary sheltering?	Family
				Ending	20-When did you finish temporary sheltering?	Family
Temporary Human Settlement Architecture After Disasters (Fallahi 2008)	Permanent sheltering started quickly because temporary sheltering with regular inspections from government finished quickly	Inspections	Number/quality of inspections	How many times	21.How many time did NGOs inspect per month	Family
				How long	21. How long was each inspection?	Family
				How many people	21. How many people were coming for each inspection?	Family
Temporary Human Settlement Architecture After Disasters (Fallahi 2008)	Family members because of living close to their collapsed building after earthquake were helping for transitional sheltering.	Survivors collaboration for temporary sheltering	Distance between temporary sheltering and transitional sheltering.	How far	22. How far was your emergency shelter from your transitional shelter?	Family
						Family
Earthquake, north of Pakistan (ref)	Waste of money because of temporary infrastructures in camps	Different between temporary sheltering cost in camps and survivor's land	Cost for land preparations	How much?	how much was the cost for land preparation and constructions for each camp	Emergency Responders
			Cost for general services cost	General services cost	How much was the cost for general services in each camp?	Emergency Responders
			Cost for infrastructures	Construction cost for infrastructures	How much was the cost for infrastructures in each camp?	Emergency Responders
			Security cost	Security cost	How was the cost for security in each camps?	Emergency Responders

As it was mentioned questions comes from different situations of survivors that other researchers have used related to temporary sheltering. There are, a lot of questions in table above which might not be useful for this research. For this research questions are designed for different groups. Some questions are designed to ask from people who were living in camps, some for those who were living in their private lands, some questions targets families as survivors some responders. In fact this research out of many books, articles and other resources related to post-earthquake scenario selected questions that are designed for development of temporary sheltering, however this research focuses on developments of emergency sheltering and designs a questionnaire to ask from people who experienced real situation.

2.2.2 Action: In the second step of the methodology, this research implemented the output of the Volume A in to practice employed different methodologies for the theoretical and practical sections. The research is based on a balance between conceptual and practical approaches. Below is the actions which this research took for this practical research.

Workshops: The methodology cycle of this research is designed to ensure a common basis for qualitative research, dealing with theoretical and conceptual issues. Volume A of this research consist of theoretical discussions and Volume B includes practical experiments through prototyping and conducting workshops. Integration of people with this research helps to identify their abilities and common skills. Different workshops and meetings in academic and non-academic environments of Manchester and Tehran maximise the potential of selected familiar forms, structures and materials from the public domain for efficient public engagement.

Each workshop in the Manchester School of Architecture started with introducing qualitative methods and techniques and to initiate the design research followed by 3D modelling and prototyping in small and actual scale. In order to organize the research activities, students selected one of the two fields including surface and strut emergency shelters so that the large group was divided. These two groups were divided into four sub-groups of three to five students each for different activities.

At the end of the workshops, the process and outputs of their work were reviewed through discussions about the prototyping process. Following this all of the prototypes were assessed and improved. Finally, at this stage of the research assessment was undertaken with a selection of random non-specialists in public spaces. The prototypes were tested by these non-specialists, architecture students as trained volunteers and school children in actual scale.

Workshops had the same process. It started firstly with briefing students and sketching their ideas. Secondly digital modelling of their designs to see the form of the outputs, thirdly small scale modelling to evaluate deployability and potential of application in post-earthquake scenario and finally actually scale modelling to test and evaluate stability, durability and erectability by non-specialists.

Seminars: This research has conducted two types of seminars. The first type was seminar for undergraduate students in Manchester School of Architecture and Beheshti School of Architecture. Students in these seminars after each workshops discussed about the outputs of their works in terms of potential of those models as self-construction emergency shelters, advantages and disadvantages of applied structures and materiality. These workshops are documented in Volume B pages 26-32.

The second type of seminar was for group of experts in Beheshti University who mostly had professional experiences in different emergency organization. This type of seminar was conducted in March 2015 when outputs of this research were shaped and documented. In this seminar the author presented the research through

PowerPoint presentation then students and academic staff who were first and second year leaders of disaster reconstruction and development commented about the work.

Conference Papers: The author also has presented outputs of different chapters as conference papers in three conferences including; Council of Educators in Landscape Architecture, Sheraton Hotel, Los Angeles, USA, April 2010 2- Academy of Architecture, St-Petersburg University, Russia June 2011, 3- UMASS, University of Massachusetts, Amherst, USA, April 2013. In these conferences the author met groups of experts and discussed about different researches.

2.2.3 Feedback: In the third step of the methodology cycle, different activities are designed as a way to get feedback. Firstly, there are some questionnaire forms with some multiple selection questions for effective feedback. In the feedback, forms are designed in two separate formats, including those for experienced people from the emergency services to comment on research outputs, and volunteers who are able to test those prototypes.

Secondly, this research, to assess and evaluate the possibility of self-erection emergency shelters, tested the shelters with different groups of users such as schoolchildren, university students and non-technical volunteers out of university. The outputs of these tests with different age groups affected the prototypes to design a self-erection emergency shelter for survivors. This feedback from different people and groups would be effective in emergency sheltering to improve the quality of life in post-earthquake periods.

Thirdly, the research implemented virtual methods such as digital modelling and computer simulations as the first method to evaluate prototypes under real conditions to predict the reaction of material and structural options before prototyping.

Finally, an important seminar in March 2015 about this research in the Beheshti University, School of Architecture has been conducted with students, including first year, second year of the MA Disaster Reconstructions, PhD students, and staff, including MA program leader, first year and second year MA program leaders, attended. At the end of the presentation students and staff including Dr Fallahi and Dr Motavaf who was the 8 years Iran- Iraq post war reconstruction leader in the Housing Ministry 26 years ago, critiqued this research which caused improvements in prototyping, secondary material options, climate issues, material sustainability.

2.2.4 Developments: In the fourth step of the methodology (development), the outputs of the experiments, public engagement events, assessments through different user groups and feedback from experienced people have caused further developments in different issues of the research. Accordingly, these developments and corrections were simulated virtually through different software such as AutoCAD before it was prototyped at full scale. These developments occurred in different issues of emergency sheltering including material and method, structural efficiency and sustainability in energy and material use.

2.3 Theoretical framework for the research methodology cycle

The aims of this study were influenced by UN provision and research methodology by different research methods related to temporary sheltering in post-earthquake scenarios. Temporary sheltering is an important stage to support the physical, psychological and social needs of survivors in post-earthquake scenarios. As previously mentioned in the Literature Review, some NGOs, such as UNDRO believe that temporary sheltering should respond to low cost units as well as physical and psychological needs (Winandy, 2006).

For responding to these needs, temporary sheltering should have a unique and general approach. Different approaches and methods from international responders on the one hand and variety of situations in different countries with different geographical, climatic, cultural conditions on the other hand, make it more complicated. Therefore, these different situations effect negatively on responding, reconstruction and developments.

Habitat mentions different stages of disaster response as a cycle. In this cycle, all of the activities try to minimise the required time to bring survivors back to a normal life. Therefore, sheltering in this cycle plays an important role. Local authorities and international NGOs should improve services related to temporary sheltering to maximize welfare for survivors. During the process of reconstruction, temporary shelters are vitally important as they generally provide spaces for working, resting, treatments, relaxing, caring for old and young people, storing and other related activities (Habitat, 1994).

There are different approaches on emergency sheltering. In research from Chalinder (1998), the importance and effects of political, ecological, economic, social and psychological issues in temporary sheltering have been discussed. Generally national action for preparing disaster response cycle in each country leads to more efficiency in temporary sheltering strategies. During preparation emergency NGOs can evaluate the situation better, they can prepare to respond urgently to survivors immediate needs.

In addition, planning a local strategy for temporary sheltering is one important approach for Cuny (Cuny et al., 1983). He explains as below:

> “Emergency sheltering and transitional sheltering are not different series of shelter units next to each other for families. It is a big unit for settlement that through time effects on society, security, environment and neighbourhood etc.” (Cuny et al., 1983:52). (Ref) (find cunny is person or uni)

Furthermore, a temporary shelter is not only a settlement place for families, it can be used for different purposes in post-earthquake scenarios. Temporary sheltering as expanded in previous chapter could be in different formats. Firstly, it can be in the format of camps that consist of emergency shelters and transitional shelters in different locations of the earthquake scenario. Secondly, settlement can be through evacuation of an earthquake area. In some cases public buildings which are in good condition after an earthquake can be used as crisis points for emergency NGOs and survivors (Quarantelli, 1995).

Efficient temporary sheltering in post-earthquake scenarios for the disaster response cycle and reconstruction can strengthen social trends. Cuny believes that NGOs should have specific frameworks for their response to plan their activities in different stages of the disaster response cycle and reconstruction according to different situations (Cuny et al., 1983).

There are different issues that should be responded to in every post-earthquake scenario. These issues are the gaps between emergency sheltering, transitional sheltering, and permanent sheltering. Secondly considering emergency sheltering as a necessary step for temporary sheltering and finally, stability and efficiency of temporary shelters and the role of local authorities/ NGOs in reconstructions.

After an earthquake, the biggest concern for NGOs and local authorities would be to bring normal conditions back within a post-earthquake scenario in minimum time. According to the Red Cross World Disaster Report in 2001, there is a need for an efficient management that is based on social and scientific research for the disaster response cycle and reconstructions.

2.3.1 Methods of temporary sheltering

The methods of temporary sheltering depends on different conditions in a post-earthquake scenario. Some of these conditions are:

- Scale of earthquake,
- Locations of earthquake including climatic, geographical and historical conditions.
- Conditions of local people including economy age, etc.
- Public skills for disaster prevention practice and their ability
- Level of damages and local methods of construction before earthquakes (Fallahi, 2007)

Selection of efficient and suitable methods for temporary shelter improves the quality of lives in a post-earthquake scenario. There are two approaches for this research; the first approach is public engagement and the second approach is implementation of technology. However, the implementation of technology in some geographical locations for various reasons might not be available. Therefore public engagement for this research counts as a high priority because it is available in every urban and rural area.

For UNDRO, the possibilities for temporary sheltering are different types of tents for emergency sheltering and porta-cabins for transitional shelters. Out of all of the different methods of temporary sheltering, tents are the most efficient equipment that emergency services use. Tents have many advantages including being lightweight, of small size, easy to move and erect. However, tents have disadvantages including deformation in short time in comparison with transitional and permanent shelters. Therefore, it cannot be an efficient option for long term sheltering and protecting the personal belongings of survivors.

Below are situations of displaced people following an earthquake. There are different approaches of temporary sheltering from experts and organizations in world scale such as United Nations, World Bank that are mentioned below.

OCHA[36]: Emergency sheltering consists of six situations in a post-earthquake scenario. The situations are Host-Families, Urban Self-Settlement, Rural Self-Settlement, Collection Centre, Self-Settled Camps, and Planned Camps.

These six situations of people who are displaced from their permanent shelters is provided below. Movement of survivors after risk reduction in the post-earthquake scenario can be in the long term.

No	Group	Description
1	Host-Families	Settlement in house of family, friends and relatives
2	Urban Self-Settlement	Settlement in urban areas through living in public places with infrastructure
3	Rural Self-Settlement	Settlement in rural areas and living in public places with infrastructure
4	Collection Centre	Settlement in these public spaces are generally public buildings that are survived from earthquake
5	Self-Settled Camps	Survivors live in a camp made by local people
6	Planned Camps	Survivors are going to live in predicted camps. Local authority or NGOs would deliver different services.

Table 1.2: *Categorization of displaced people (Keen, 2008)*

[36] UN Office for the Coordination of Humanitarian Affairs

Academic experts from Beheshti University (Iran): Dr Fallahi[37] categorizes emergency sheltering in three groups. Firstly, providing camps is one of the efficient methods for temporary sheltering in post-earthquake scenarios. In this method at the beginning, they choose an open area close to an earthquake scenario. Then they prepare and equip selected land for temporary sheltering such as levelling the site or preparing car, truck, emergency routes etc. for easy access to camp. According to climate condition, budget, the number of survivors and the scale of the camp could be different.

A second group would be irregular planning. In this type of temporary sheltering survivors would be able to decide where to live for a short time. Experience from the Bam earthquake shows that 70% of survivors had preferred to live close to their collapsed houses.

A third group is a combination of the first and second group, survivors are close to their collapsed permanent houses and they can use indoor and outdoor public spaces to live as a group. (Fallahi, 2008)

World Bank: According to the World Bank's view in 2010 temporary sheltering must be categorized into two groups. Some of them move to camps and some of them stay close to their collapsed houses because survivors after an earthquake try to make their situation stable. These two situations might be short term or long term. People in an earthquake are affected in the same earthquake scenario but they react differently because their conditions would be different. Some people might start to reconstruct soon while other people might start late. Even it might take months or years. (OCHA, 2008).

2.4 Selected framework for this research

All of these sections might affect the type of questioning from survivors and experienced disaster response cycle. Targeted families might be from different groups. Therefore, identification of these differences are important.

This research is concerned with different theoretical frameworks but implementing and considering all of the mentioned theoretical frameworks from different experiences and situations is not possible. However, this research studied those frameworks and methods that are more efficient and relevant to temporary sheltering in Bam.

The people selected for questioning and interviewing for this research are the Bam earthquake survivors and people who directly engaged with decision makings during the Bam earthquake. Most of these people benefited from reconstruction experience of villages and cities during eight years of the Iran- Iraq war. It is important to mention

[37] Reconstruction leader in Beheshti University (National University of Iran) and one of the reconstruction leaders of Bam earthquake.

that the selected framework for this research is related to two groups of survivors including firstly, settlement in camps and secondly survivor’s properties (land.

Survivors in Bam mostly preferred to stay in their private land and close to their collapsed buildings where mostly were palm gardens. However, emergency NGOs, because of health and safety, security and quick medical treatments moved some of the survivors to the prepared camps. Settlement in camps had some problems such as: access to their private land was difficult due to distance between camps and the location of their collapsed houses. Secondly, they had to experience new environment in the camp with different social structure. As expanded before in The Bam and Baravat they were living in neighbourhood of families, friend but in camps they had to live next to the camp of strangers and new neighbours. Changing social structure of a society in emergency situation and short term might be harmful but for mid term and long term might cause more damages.

Furthermore, camping in a selected site, which is not designed for temporary sheltering needs foundations and infrastructures such as primary and secondary roads, security units. Designing a camp and providing in infrastructures after earthquake cause spending more damages.

2.5 Chapter conclusion

In conclusion, this chapter discusses the structure of this research and the different activities that are planned for four stages of the research methodology cycles. Generally, data collection starts through fieldwork surrounding temporary sheltering in Bam and different issues related to temporary sheltering in the disaster response cycle, structural design and material design.

One of the important developments in this chapter is the methods and techniques applied to the self-erection of emergency shelters by survivors (x ref). Different questions and research frameworks focus on the different issues of emergency sheltering to identify problems and areas that have the potential to be developed (x ref). These issues cover different areas including erection problems of the shelter, their requirements, length of erection, etc.

The questions designed in this chapter (x ref) target families as a basis of societies to evaluate depth of the gaps. Fieldwork helped this research for data collection and links this research to people who have experienced different problems. They were asked about different issues related to emergency sheltering. These questions focused on the location of living to experience of temporary shelter which they experienced. Questions focused on length of temporary sheltering, number people in to accommodation, their security, neighbourhood, public services. (x ref). Reference of these questions are the lessons learnt from previous earthquakes that are mentioned in the questionnaire table (x ref). Development in quick erection and mobility of emergency sheltering in this research is the result of finding depth of the gaps and direct communication with survivors, to identify their immediate needs. Furthermore communication with emergency NGOs and the personal experience of the author are other factors which helps to respond to identified gaps in this research.

The disaster response cycle, consists of different stages and activities(x ref). However, the research focused only on emergency sheltering and activities related to the immediate architectural needs, which has a global strategy to respond in a post-earthquake scenario. The research methodology cycle covers and gives direction to the different activities in each step. Different research methods are planned for data collection, discussion and prototyping.

The outputs of volume A are translated from theory into practice and it is documented in a portfolio, which is presented as volume B. There is a methodology for design works that is expanded at the beginning of the portfolio. Finally, this research examines the strategy of emergency sheltering and outputs are designed for a short term quick response. In the next step survivors would be able to upgrade their shelters for more sustainability. Sustainability of emergency sheltering is discussed in 3 areas including the earthquake response cycle, structural design for emergency sheltering and material design for emergency sheltering. Finally, the practical part of research prototypes shelters through low-tech familiar and traditional methods to simplify emergency sheltering for survivors with limited technical skills.

Chapter 3
Bam fieldwork

3.1 Introduction

In this chapter firstly general information about Bam including its earthquake and social, geographical, economic and industrial conditions, are expanded on then this research focuses on emergency sheltering during the Bam earthquake.

3.2 Bam before earthquake

- Geographical location of Bam

Bam is located in south-east Iran and east of the Kerman province with an area of 19,480 km^2. The height from sea level is 10,760M and from the north is connected to the city of Kerman, south to Kahnooj, west to Jiroft and from east is neighbour to Blouchestan province (Ramazi and Jigheh, 2006)

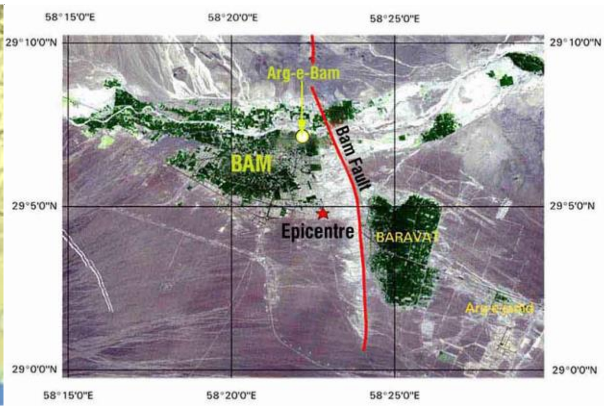


Figure 3.1: *Geographical location of Bam in Iran, Ref: http:www.farsinet.com/bam*

Figure 3.2: *Satellite image of Bam and Baravat, Ref: http:www.earth-auroville.com, Access date: 12/06/2015*

The population of Bam in 1986 was 157,682 that with 2.13% growth a year increased to 198,090 in 1996. According to the latest statistics, the population of Bam in 2003 in the urban area was 109,487, and in the rural areas was 116,312. The county of Bam has two historical cities called the city of Bam and the city of Baravat. Furthermore, during the last decades another three villages have emerged that are called Fahroj, Narma-Shir, Mohamad-abad because of the increasing population and are attached to Bam. The population of these three areas are 4,252, 3,248 and 2,965 people respectively. In total, according to the latest Kerman province-census the population of Bam County in 2003 are as below:

Location	Number of person	Number of families
City of Bam	88,000	17,000
City of Baravat	17,000	3,000
County of Bam	223,000	41,000

Table 3.1: *Population of Bam County before earthquake in 2003 (Fayazi, 2011)*

- **Social conditions of Bam**

The people of Bam are moderate Muslim people who were talking with Bami and Balouch Persian accent. According to the national registration office in 2016[38], 88.3% of people in Bam are Shia and Suni Musim, 11% Zoroastrians 4% Christians and 3% Jewish people. The people of Bam, as other Iranians, benefit from a rich culture and civilization. For example, there are many historical traditions, which come from Persian civilization such as Yalda night[39], Nowruz[40], special wedding proposal by men, Charshanbe-soori[41] and funerals etc. Furthermore, as a sign of the Bam civilization and identity, the historical “Bam citadel”, which was the biggest mud brick citadel in the world, can be mentioned.

- **Climate condition and geology of Bam**

Bam is located in a hot and dry climate in Iran. The minimum air temperature in Bam -7.5 centigrade and maximum temperature +52 degrees centigrade are registered. Bam County has experienced a different number of earthquakes in different scales during the last 50 years, which is the sign of its location in the earthquake fault but there has never been any earthquake in the city of Bam that could threaten the stability of the Bam citadel throughout its history.

Date	Richter scale	Time	Dimension X	Dimension Y
29/06/1956	4.5	02:18:27	28.5	57.25
16/10/1963	4.6	19:02:00	28.8	58.0
11/05/1964	5.1	06:07:41	28.3	57.4
10/08/1964	4.7	18:18:41	29.8	57.7
28/04/1967	4.8	19:38:29	28.3	57.5
02/07/1969	4.9	21:27:29	28.2	57.2
10/04/1970	4.7	22:04:06	28.4	57.5
09/08/1970	2.8	07:45:12	28.6	58.9
05/07/1984	5.7	13:53:14	29.5	57.5

[38] Statistic centre of Iran, https://www.amar.org.ir/ Access date: 25/11/2016

[39] Party over the longest night of the year in winter.

[40] Beginning of spring and Persian New Year.

[41] Firework over the last Wednesday of Persian year.

Table 3.2: *Recorded earthquakes in Bam County (Fayazi, 2011)*

In terms of water resources, Bam benefits from underground and over ground water resources. According to local authority statistics in 1985 underground water resources of Bam include 317 qanats[42], 374 deep water shafts, 89 half-deep water shaft and 16 natural water resources (Fayazi, 2011).

- **Economic situation of Bam**

The economy of Bam is mainly based on agriculture and Bam is one of most productive cities in the Kerman province in terms of agriculture. Products are citrus including orange, lemon etc., henna and dates from different parts of city. In addition, different types of oil plants such as sunflower and livestock plans are supporting 51% of the agriculture industry in Bam. Livestock is the second industry in Bam, which supports the local economy (Fayazi, 2011).

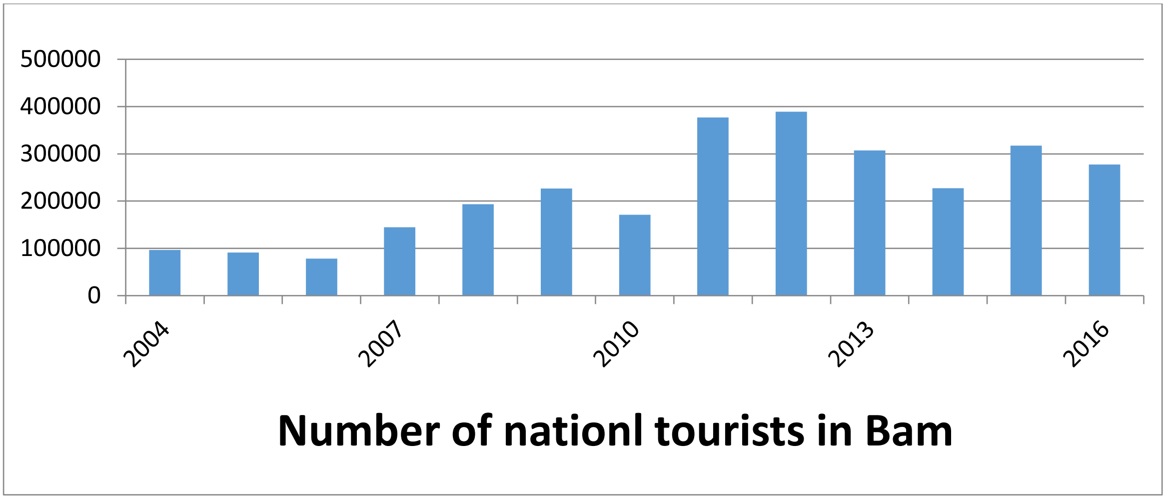
Garden products including dates and citrus provide 6.5% of the province agriculture. The amount of dates produced in Bam is 120,000 tonnes per year of this more than 3,000 tonnes would be exported to different countries. After dates, citrus is the second product from Bam. Generally, daily life and the economic situation for the majority of local people in Bam is based on agriculture; in which 25% of people are engaged with different agricultural jobs. Approximately 4,000 hectares of the city of Baravat, which is 10km far from Bam, are palm gardens. In addition, approximately 70% of milk in Kerman, as centre of Kerman province, are produced daily in Bam (Abadi, 2004).

Finally, according to the United Nations, Kerman province was struggling with many problems before the earthquake such as drought, unemployment, illegal Afghani refugees who pass the border to work in Bam, illegal drug mafia from Afghanistan. The percentage of unemployment in Bam before the earthquake was 25%. Other statistics from the UN say that 90% of people in the urban area and rural areas had access to drinking water, 44% had access to local health system and 95% had access to health services in Bam County.

- **Industrial and touristic conditions of Bam**

The city of Bam benefits from the 2,000 years old Bam citadel, which is a UNESCO world heritage site and also a new adventure park from 1993 known as Arg-jadid in 2100 hectares. With starting reconstruction of the citadel after Bam earthquake, number of tourists fluctuating. Political and economic conditions are effective in number of visitors in Bam. The chart below shows number of national and international visitors during Bam reconstruction.

[42] Qanat is an ancient method of transferring water from mountains areas to desert which is UNDECO registered method for farming in Ancient Iran as an human heritages. http://whc.unesco.org/en/list/1506



(Ref: Governor of Bam website https://gov.kr.ir Access date: 24/06/2017)

(Ref: Governor of Bam website https://gov.kr.ir Access date: 24/06/2017)

Nine industrial units were established in Bam County between 1983 to 1992 and local government established another 55 industrial units between 1992 to 2002; all of those units stopped working after the Bam earthquake in 2003. (Fayazi, 2011)

- **Ownership of buildings in Bam**

The Housing Ministry of Iran released the number of registered permissions for housing in Bam between 1996 – 2002. In 2002 the number of issued permission for housing was 16,215 residential buildings in Bam and 2,759 buildings in Baravat. There is more detailed information related to used materials for housing which are expanded upon below. Statistics from the local authority shows that in Bam 74% of people are the owners of their building that they were living in before earthquake and this ownership in Baravat was 81%. The percentage in rural areas gets to 86% (Fayazi, 2011).

Location	Ownership
County of Bam	81%
City of Bam	74%
City of Baravat	81%
Rural areas	86%

Table 3.3: *Percentage of building ownerships (Fayazi, 2011)*

3.3 Bam after earthquake

As expanded in the Literature Review (section 1.7), Bam earthquake occurred at 6.5 on the Richter scale on Friday 26th December 2003 at 5:26am in local time. The centre of the earthquake was in Bam. It destroyed the 2,700 year old Bam citadel and the city of Bam in seconds. This earthquake left 22,391 deaths, 8,136 injured and 422 disappeared persons only in Bam. There are 3810 deaths, 1,711 injured and 124 disappeared in Baravat. There are many human and economic losses reported from villages around Bam and Baravat. (Ramazi and Jigheh, 2006).

Construction and building conditions in Bam before the earthquake, because of ignoring national buildings rules and regulations[43] by constructors, local people and lack of inspection from Iranian Ministry of Housing or local authority, were not earthquake resistant. Only a few buildings in Bam, which mostly were governmental buildings did not collapse which were constructed under “Standard no 2800” rules and regulation. The majority of the buildings, which were made by clay, bricks, mud-bricks with no post and beams collapsed in the earthquake (Fayazi, 2011). The figure 3.3 shows level of damages in different part of Bam that are categorized in three groups of 20-50% damage, 50-80% and 80-100% damages.

Figure 3.3: *Building damages after Bam earthquake (Abadi, 2004)*

[43] “Standard No 2800”

Dr Fallahi in his article writes that the Bam earthquake is one the most terrible earthquakes in contemporary history of Iran because of the reasons mentioned below (Fallahi, 2007).

1- **Time of the Bam earthquake:** The earthquake happened in 5:26 in the morning when most of the people were asleep. This time of the day, most of the people do not have anything to do out of the building. Therefore, people did not have time to escape and were trapped in their houses.

2- **Day of the Bam earthquake:** In Iran generally people work six days a week from Saturdays to Thursdays and Fridays are weekends. Unfortunately, the earthquake happened on Friday, which is an off day and resting time with their families.

3- **Length of the Bam earthquake:** According to survivors, they were tremors between 12 to 17 seconds. If we calculate the average like 14 seconds, it would be two times more than a normal earthquake.

4- **Direction of the Bam earthquake:** Bam earthquake is one of the uncommon earthquakes in the world that happen rarely because it shook buildings in different directions.

5- **Centre of the Bam earthquake:** Throughout history in Iran the centre of earthquakes mostly have been out of the city or in rural areas. Therefore, most of the time rural areas were damaged but the centre of Bam earthquake was in city of Bam and it caused more damage.

6- **Radius of the Bam earthquake:** According to American Earthquakes Centre, the depth of the Bam earthquake was 10km from the earth's surface. Therefore, the radius of the damage was 15km around the fault. Out of this radius buildings were not damaged seriously.

7- **Climate conditions of Bam:** Bam because of its location, which is close to the desert has a very cold and long winter and very hot and long summer. Out all of the months in a year, December is the coldest month over a year and the earthquake happened on 26th December.

8- **Human cultural heritages in Bam:** In Bam economic and human losses on one side was one the tragedies in national scale. On the other side serious damages to Bam citadel, as the biggest mud brick citadel and one of the Iran's world heritages registered in UNESCO, was a global tragedy.

9- **Three minor pre-earthquakes:** Three minor pre-earthquakes is one of the rare events in geophysics science. According to local people a night, before the Bam earthquake between 9 pm to 4 am three times a minor earthquake happened that was the reason of fear between local people. This fear between some local people caused them to survive the earthquake.

3.3.1 Population after earthquake

The populations of Bam and Baravat before earthquake were 89,145 and 15,324 and because of the earthquake 25% of the population in Bam, which is 22,391 and, 7% of population in Baravat, which is 1,112, lost their lives.

3.3.2 Taxonomy of local building materials

- Traditional buildings: This type of building usually consists of a dome made by mud, clay, mud bricks and wood.
- Buildings made by cement bricks: This type of building in some small cities from inspections by Housing Ministry, is weaker than in big cities where is more common. 100% of this type of buildings in the Bam earthquake completely collapsed.
- Buildings made by bricks: This type of building in comparisons with previous type is stronger but because of the bad quality of housing, which is the reason lack of regular inspection from Iranian Housing Ministry for acting National Building Codes (see section 1.7), more than 80% of buildings were damaged seriously.
- Buildings made by steel structure: This type of building same as previous groups because of wrong engineering methods such as poor connection methods of post and beams, caused damages.
- Building made by concrete structure: The most important reason of damages of this building type were application of wrong concrete construction methods. Human losses in this type of buildings and building made by steel are more because of collapsing heavyweight materials (Fayazi, 2011).

As mentioned before, because the centre of the earthquake was located in the city of Bam and constructions where out of national rules and regulations, most of the buildings in different types that are mentioned above were collapsed.

3.3.3 Delivering temporary shelters

One of important issues in temporary sheltering in a post-earthquake scenario is identification of survivors and their families who need an emergency shelter as soon as possible. Therefore, an efficient management plays an important role to identify and prioritise survivors by need. The Ministry of Interior of the Republic of Iran accepted providing and delivering emergency shelters to Bam and the management of the post-earthquake scenario and the local authority was responsible to identify, prioritise and deliver emergency shelters from crisis points to survivors. Tables below show the number of contracts that the Ministry of Interior of the Republic of Iran made with different organizations to provide temporary shelters (Fayazi, 2011).

Emergency shelter supplier	Number of emergency shelters	Description
Housing Foundation of Islamic Revolution	5600	2800 units of 18 square equipped with kitchen, toilets and bathroom. 2800 units of 20 square equipped with kitchen, toilets and bathroom.
Defence Ministry	5600	
Rashestan Company	5000	
Sahab-Farhangian Co	2500	
Hadafkaran-Kimia Co	2500	
PVC Co	2500	
Seyedi Co	2500	
Baharestan Co	1875	
Total	28075	

Table 3.4: Initial plan for emergency shelter supply on the first day of the earthquake (Fayazi, 2011)

<table>
<tr><td rowspan="4">Total number of emergency shelters in different contracts
35075</td><td rowspan="3">Completed number of emergency shelters</td><td rowspan="3">33981</td><td>In survivor's lands</td><td>24931</td><td colspan="2"></td></tr>
<tr><td rowspan="2">In camps</td><td rowspan="2">9050</td><td>Occupied units</td><td>3700</td></tr>
<tr><td>unoccupied units</td><td>5350</td></tr>
<tr><td>Uncompleted number of emergency shelters</td><td>1094</td><td colspan="4">N/A</td></tr>
</table>

Table 3.5: Occupation situation of emergency shelters (Fayazi, 2011)

For identification of survivors, prioritizing and delivering temporary shelters, some stages of the disaster response cycle are very important such as rescue, emergency medical treatments, emergency sheltering etc. For responding to these requirements efficiently, a few days after the earthquake some coupon books were prepared by the Iranian Red Crescent to give to survivors. It helped to manage aid between actual survivors and prevent delivery to other people who were not in the post-earthquake scenario before and because of different reasons they moved to Bam. For instance, some families, relatives, volunteers and even robbers moved to Bam after the earthquake. These coupon books had different pages for medicine, clothes, food etc. (Fayazi, 2011).

One of the pages of this coupon book was printed for emergency shelters and one for transitional shelter. The process was the manufacturer had a contract with the government after transferring shelters to Bam, the local authority with collaboration of emergency NGOs were delivering shelters to survivors.

The Defence Ministry, because of their experience and field of expertise in management, producing and transferring different types of shelters was the first organization that responded to temporary sheltering quickly. The emergency shelter type of the Defence Ministry was just a tent and the transitional shelter was a porta cabin. The Defence Ministry was responsible for 5,600 units of temporary shelters (Fayazi, 2011).

According to suggestion, the plan for emergency sheltering from one of Iranian architectural studios[44], which engaged with Bam earthquake, most of the places for emergency sheltering are designed in empty lands in southern and south-eastern areas of Bam close to the Bam – Baravat motorway. The attached map shows identified empty lands in the city of Bam, which are close to the main routes or squares for quick and easy access.

[44] Arman-Shahr Co

As City map in previous page shows some of the planned areas for temporary sheltering are in urban areas. Emergency sheltering out of the city was restricted according to a decision of governmental organizations. However, as is expanded below, most of the big areas for temporary sheltering because of weakness of management were located in south of Bam outside the city. Firstly, most of the manufacturers delivered emergency shelters to stores south of the city and trained volunteers, because of lack of time and restrictions to use trucks or other vehicles, erected emergency shelters out of city. Because of this reason, survivors did not wish to live in camps and most of the emergency units and later transitional units stayed unoccupied (Fayazi, 2011).

As expanded before, most of the land south of Bam was occupied for emergency sheltering earlier, while emergency NGOs had planned to use these lands south of Bam for transitional sheltering. Through this strategy, emergency NGOs could start landscape recovery in Bam quickly. In addition, transitional shelters because of bigger sizes of shelters, cost more to transfer inside of city camps. Therefore, it was more efficient economically to locate them south of the city close to the Bam- Baravat motorway. The local authority decided to prioritize those families who were resident in emergency shelters in those occupied lands for transitional sheltering. Through this decision, they could evacuate those occupied lands for transitional sheltering (Fayazi, 2011).

3.4 Changing temporary sheltering approach from camp to survivor's land

A few weeks after the earthquake in Bam when the Iranian Defence Ministry, Housing Foundation of Islamic Revolution and Rashestan company finished emergency sheltering and started delivering transitional sheltering, site preparation for camps was the first important stage for temporary sheltering. Fayazi says; in this stage, the level of stress from survivors and other people who were working in the post-earthquake scenario decreased. Survivors started commenting about their situation to get better life conditions such as: they preferred to stay close to their collapsed houses and their personal belongings or to move to other cities to live with their relatives or friends. In addition, some of them were asking for their transitional shelters in their private lands and close to their collapsed building or to move into camps that are provided by international NGOs, which usually had better quality etc. (Fayazi, 2011).

As it is mentioned before after emergency sheltering, survivors were asking to move their porta cabin to their private lands that generally was a garden. They started sending letters to the local authority and Iranian Red Crescent to deliver their porta cabin there or transfer it from camp to their lands. It caused the local authority to ask for a meeting with other engaged NGOs to change the transitional sheltering approach. Furthermore, most of the planned lands for transitional shelter were occupied with emergency shelters and it was not possible to move all of the survivors to prepare camping sites for transitional sheltering (Fayazi, 2011).

Figure 3.5: Settlement of survivors in their private palm gardens (Ref: Mehr News Agency Image credit: Hamid Sadeghi)

On the other side, other experts[45] because of their experience in reconstruction and sheltering from the Iran-Iraq war were emphasizing to avoid keeping survivors in camps because they believed that according to their mid-term and long-term temporary sheltering experience, life conditions in the camp were not good. They believed that it causes many security and social problems. Secondly, if they live far from their collapsed building, it slows down reconstruction. Therefore, the local authority a few days after transitional sheltering, changed their approach from the camps out of the city to the survivor's land and different organizations that were responsible for transitional sheltering such as Housing Foundation, had to deliver and erect transitional shelters inside the survivor's land, close to their collapsed buildings.

In addition, there are different reasons that caused the local authority to change the transitional sheltering approach. As expanded above, the first reason was preference of survivors to stay away from the camps. The second reason was suggestions of the Iranian reconstruction experts that living in their gardens and close to collapsed building fasten the reconstruction process. It causes improvement in environmental and social conditions in Bam. The life style in Bam is to live in a garden city and garden is part of daily life. In addition, temporary settlement of survivors in their private lands gathered all of the neighbourhood again that usually are families and relatives in Bam. They were looking after and protecting each other. Therefore, it caused an improvement of security and social relations.

At the same time, sheltering in survivor's land had some problems too. Earthquake survivors who were generally come from wealthy families had to live in a small tents. These survivors before earthquake were living in big garden houses with their families and relatives in their neighbourhood. Problems of transitional sheltering in survivor's land were as below (Fayazi, 2011).

- Centralized earthquake response and emergency services such as responding to survivors who live in camps was easier in comparison to survivors who were in different areas of city.

[45] Such as Majid Jodi who was the chair of reconstruction department in Housing Foundation of Islamic Revolution during eight years Iran-Iraq war. Ref: Islamic Republic Iran Broadcasting channel interview with Majid Jodi in 27/08/2010.

- Bins, tanks of the toilets and baths were not acceptable in terms of health and safety and after delivery and installation was out of control and inspection for local government. In some cases it caused bad smells and attracted insects.
- The majority of the refuse was plastic forks, knives spoons, plates and other plastic equipment.
- There was the risk of biting by scorpions and snakes in gardens.
- Settlement in survivor's land makes rescue, investigation and finding trapped people more difficult.

As a result of this experiment, this research develops emergency sheltering through providing the possibility of upgrading sustainable emergency shelters for mid-term sheltering, designing simple self-erection lightweight emergency shelters for survivors to move in their private lands. Form of the designed shelters was inspired from local traditional shelters in Kerman which is familiar for survivors. Secondly shelter are designed to apply lightweight local materials. Waterproof cardboard is primary material option for short term emergency shelter which comes from local factories and palm live for mid term sustainability. These developments simplifies transportation of shelters. Therefore survivors would be able to move back their sustainable emergency shelters to their palm gardens in neighbourhood of their family and relatives. Through this development social structure would be the same as before earthquake.

3.5 Seminar by author about temporary sheltering in Bam

The author for data collection related to the Bam earthquake had a field trip to Iran in April 2015. He conducted a seminar with the collaboration of Dr Fallahi in Beheshti University with academic staff and students who were studying MA Disaster Reconstruction. The author started the seminar with a presentation about post-earthquake temporary sheltering and a question: Was temporary sheltering after Bam earthquake successful? This question was a big question and it covered different topics. It could give possibility to different staff and students to comment in their field of expertise and different areas. For example, one of the important answers was from Dr Motavaf who is the first year leader MA Disaster Reconstruction. According to his social science research that took two years after Bam earthquake, he believed that: "I look for identity of Bam in temporary sheltering and my aim is to consider where the identity of Bam in emergency sheltering and transitional sheltering is." During a discussion between students and staff the output was; some people believed that identity in sheltering can be defined with form and function. Form is more related to materials, structures, etc. function can be related to life style. For instance, people live in the same house or separate, flat or garden house, etc.

Dr Motavaf continues:

> "We (Iranian) live in different areas in our country independently in peace and no one threaten us. Everyone has a sense of his or her hometown. This sense might come from a good or bad memory. Imagine an earthquake destroys a city which is the hometown of many people. An earthquake can damage social

structure and sense of identity which is more harmful in long term in comparison with physical damages."

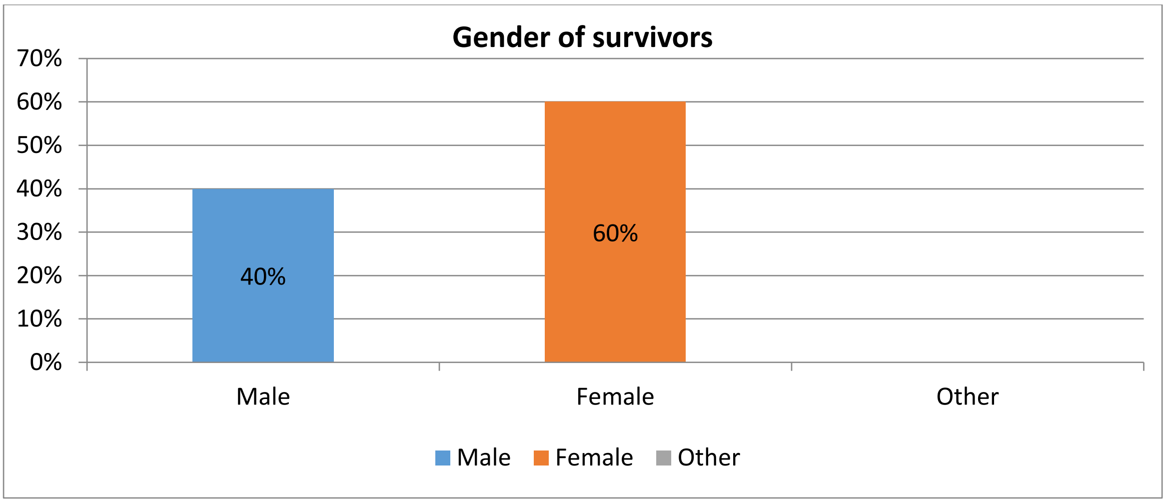
In the Bam earthquake, the aim of the local authority and other engaged NGOs were to maintain survivor's lifestyle in the local way such as living in garden houses. Regarding to Dr Motavaf comment about sense of identity, local authority started reconstruction of Bam citadel, which is one of iconic item of identity of Bam. On an international scale, Bam is known with its historical citadel and on a national scale it is known with palm gardens and citadel. These two items play an important role in daily life in Bam because the Bam citadel makes Bam a tourist attraction and different gardens make farming the most important occupation in Bam. Dr Motavaf said, when the sheltering strategy was settlement in camps it means transferring people to different areas out of their gardens with different identity and lifestyle which would be harmful in long term and therefore should be avoided.

3.6 Questionnaires and outputs

For responding to research questions accurate questionnaires, different interviews that categorize data efficiently was planned. These questionnaires targeted those survivors who were living in camps and those survivors who were living in their private lands. In the first step for better understanding the conditions of survivors, personal information of targeted people was considered in percentages. These survivors were contacted by social media because they were living in different areas 14 years after earthquake. Below is the output of this data.

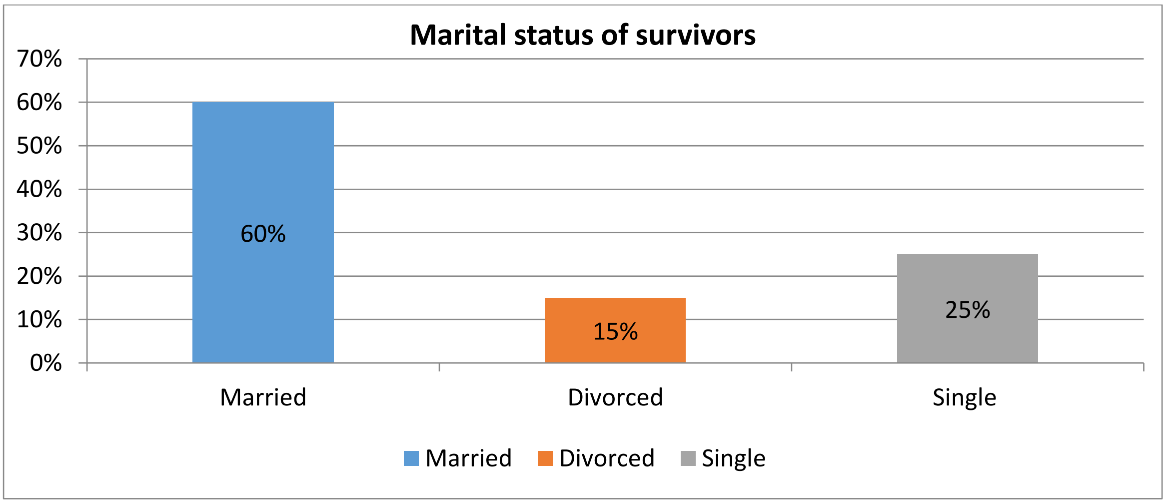
Gender			
	Numbers/20	**Percentage**	**Availability**
Female	8	40%	Yes
Male	14	60%	Yes
Other	0	0%	No

Table 3.6: *Gender of responded survivors to (Research questionnaire)*



Marital Status			
	Numbers/20	**Percentage**	**Availability**
Married	12	60%	Yes
Divorced/widowed/died	3	15%	Yes
Single	5	25%	Yes
Total	20	100%	

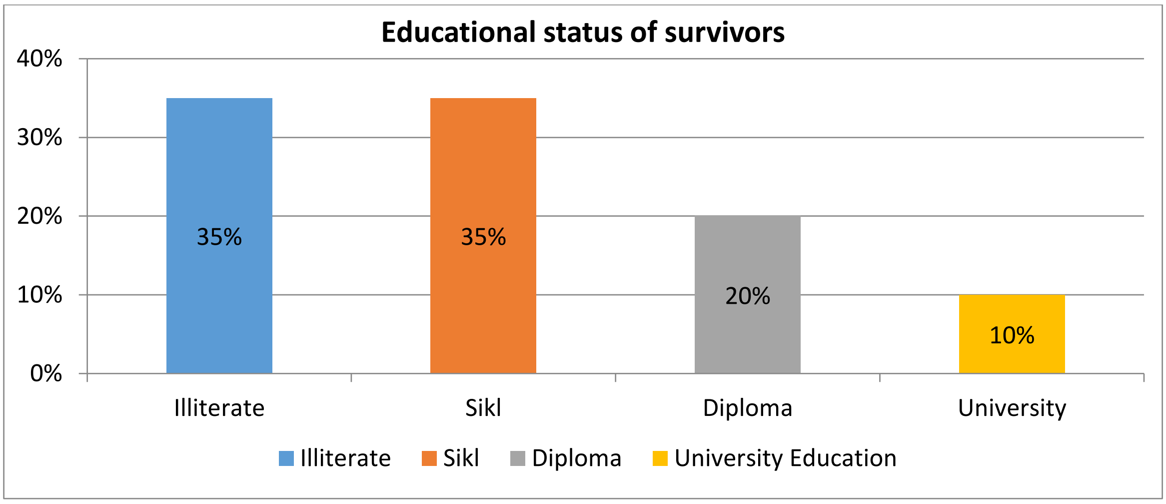
Table 3.7: *Marital status of responded survivors to (Research questionnaire)*



Educational Status			
	Numbers/20	**Percentage**	**Availability**
Illiterate	7	35%	Yes

Sikl[46]	7	35%	Yes
Diplom[47]	4	20%	Yes
University education	2	10%	Yes
Total	20	100%	

Table 3.8: *Educational status of responded survivors to (Research questionnaire)*



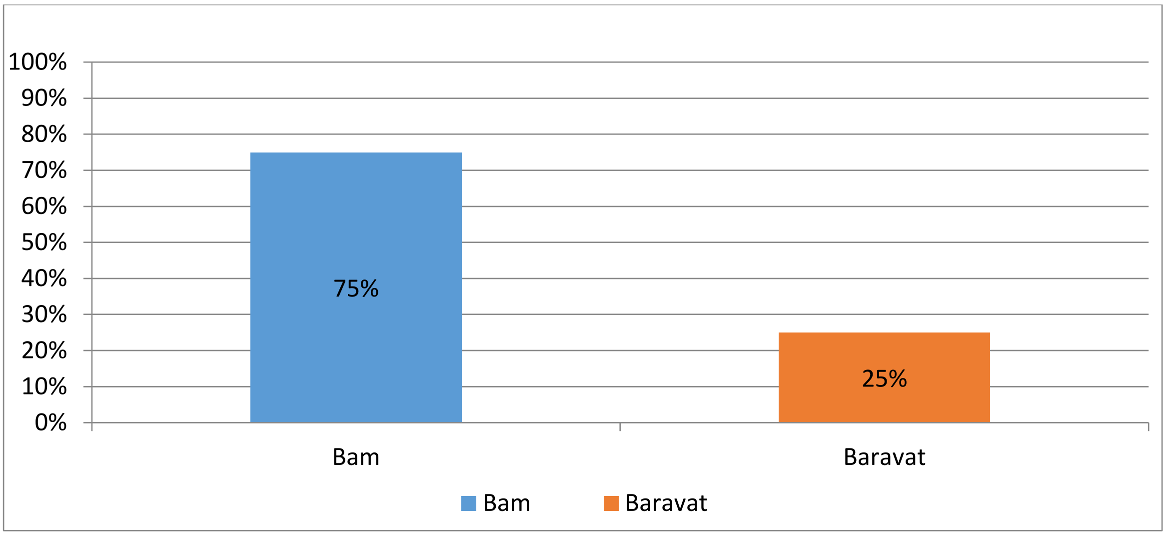
Where were you living before Bam earthquake?

Location of settlement before Bam earthquake			
	Numbers/20	**Percentage**	**Availability**
Bam	15	75%	Yes
Baravat and other villages	5	25%	Yes
Total	20	100%	

Table 3.9: *Settlement location of responded survivors before earthquake (Research questionnaire)*

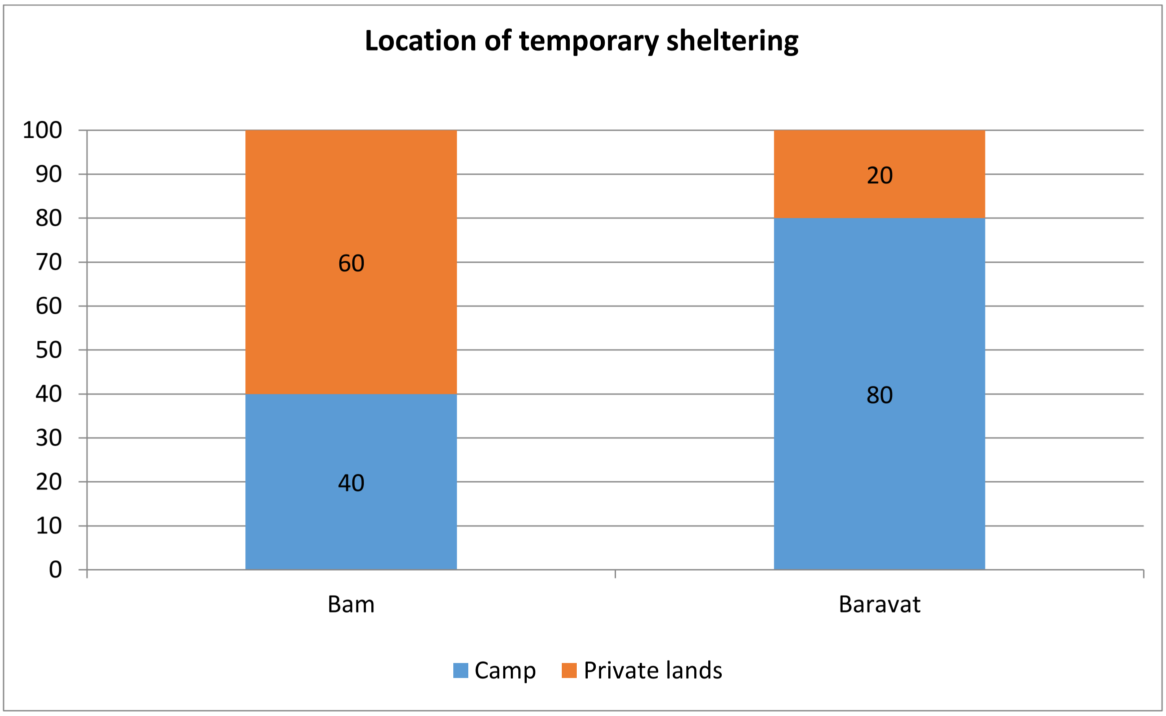
46 Sikl in Iran is name of qualification for finishing secondary school

47 Diplom is name of qualification for finishing high school



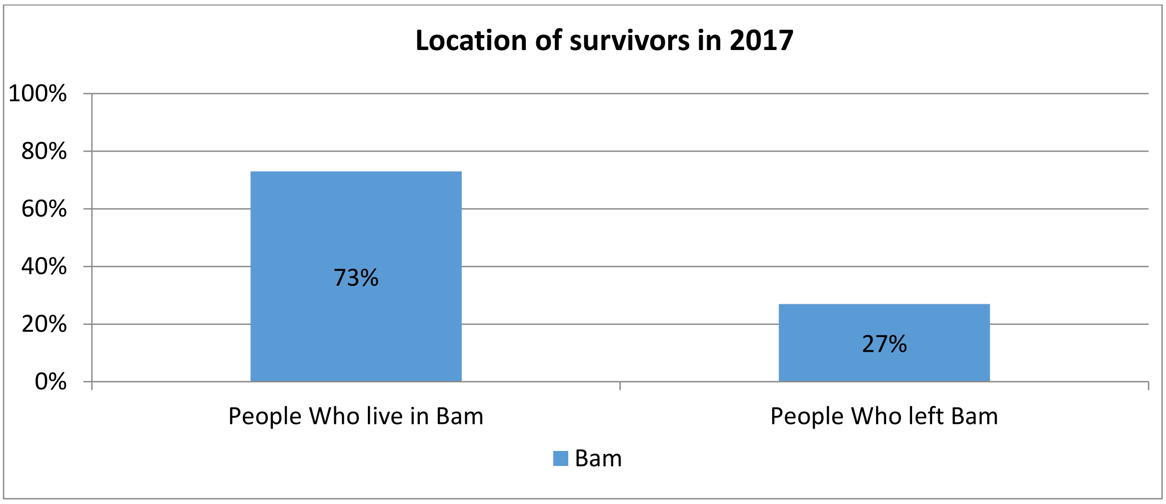
	Bam	Baravat and other villages	Availability
Camp	6	4	10
Private lands	9	1	10
Total	15	5	20

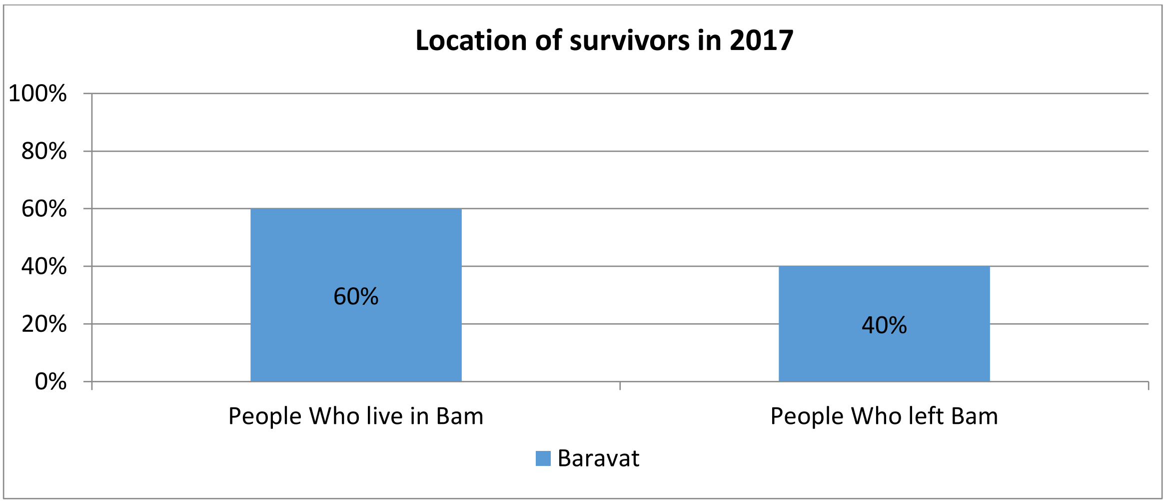
Table 3.10: *Location of survivors during earthquake and experienced location for temporary sheltering (Research questionnaire)*



Existing location of survivors after a decade			
	Numbers/20	**Percent age**	**Availability**
Bam	11	73%	15
Baravat and other villages	3	60%	5
Total	14	70%	20

Table 3.11: *Existing location of survivors before earthquake (Research questionnaire)*

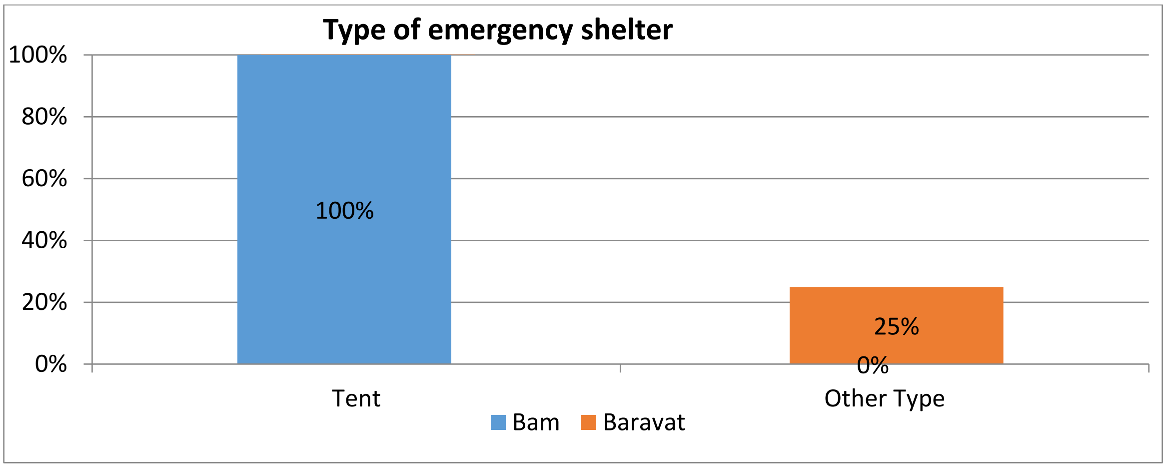




Type of experienced emergency shelters			
	Numbers/20	**Percent age**	**Availability**

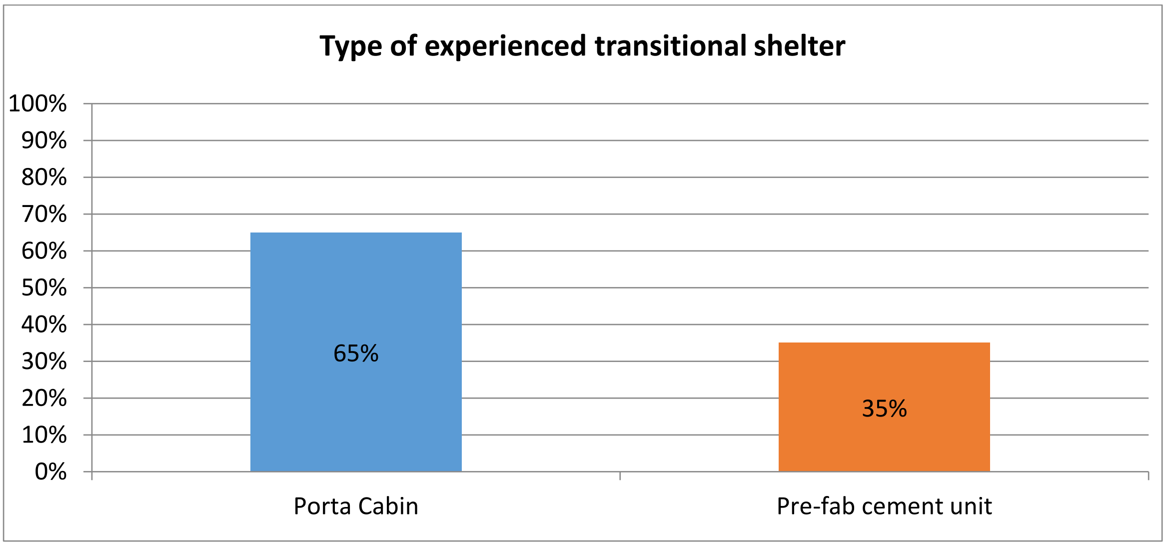
Tent	20	100%	Yes
Other type of emergency shelter	0	0%	No
Total	20	100%	

Table 3.12: *Type of experienced emergency shelter (Research questionnaire)*



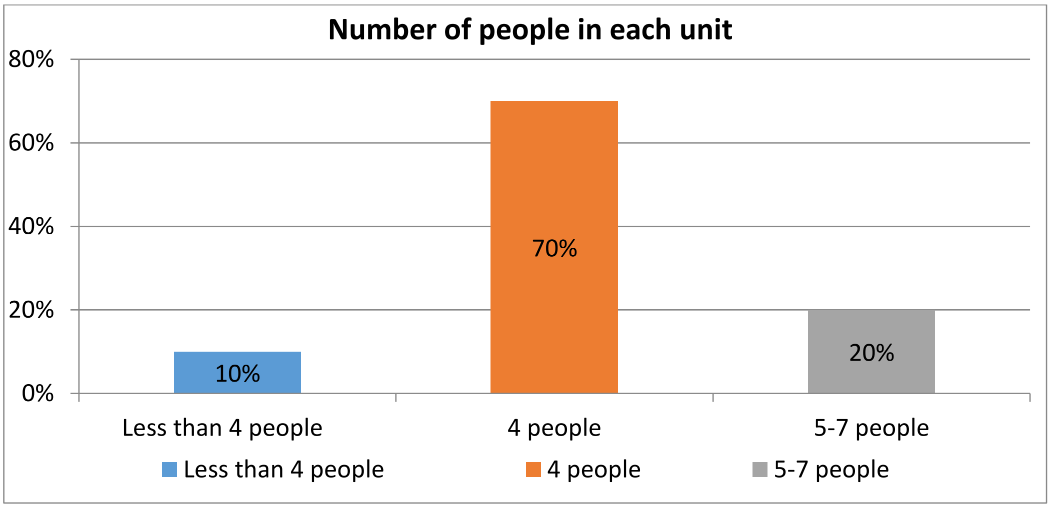
Type of experienced transitional shelters			
	Numbers/20	**Percent age**	**Availability**
Porta cabin	13	65%	Yes
Pre-fab cement units	7	35%	Yes
Total	20	100%	

Table 3.13: *Type of experienced transitional shelter (Research questionnaire)*



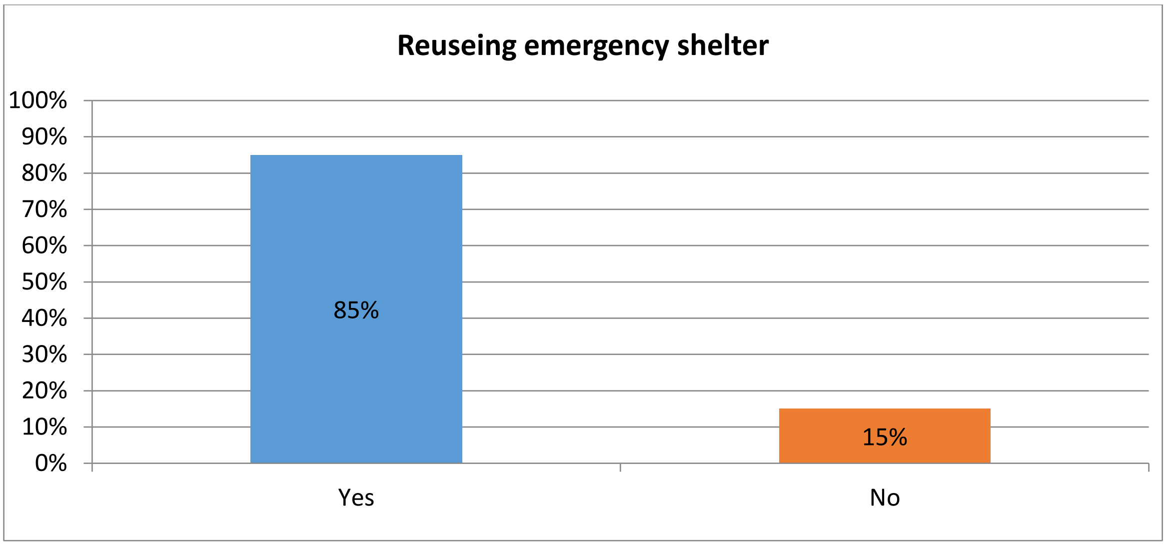
Number of people in each unit of temporary shelters			
	Numbers/20	**Percent age**	**Available tent**
Less than 4 people	2	10%	Yes
4 people	14	70%	Yes
Between 5-7 people	4	20%	Yes
Total	20	100%	

Table 3.14: *Number of people in each unit of temporary shelters (Research questionnaire)*



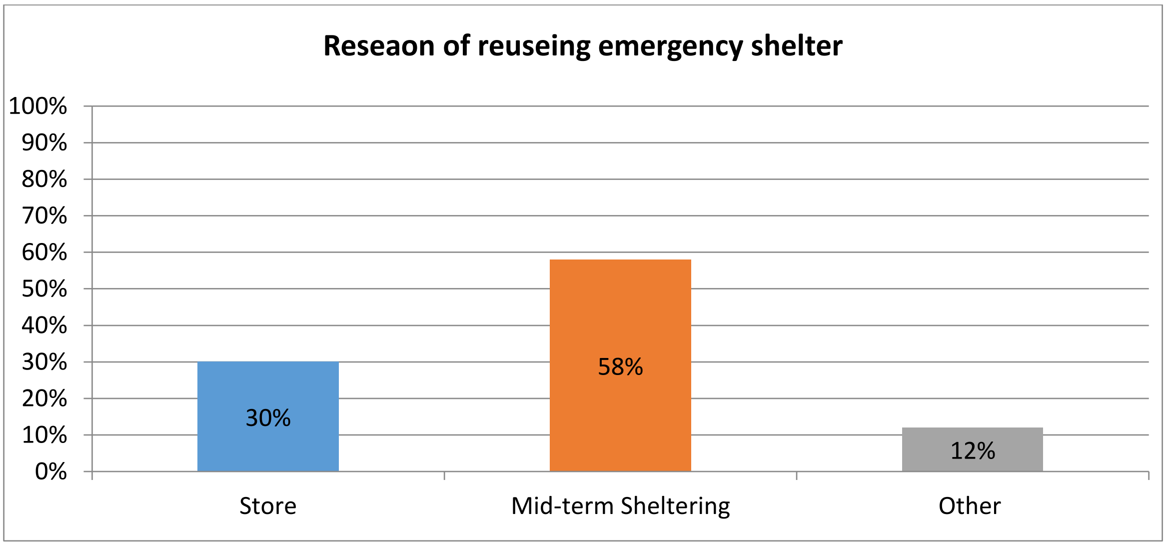
Reusing emergency shelters for other purposes		
	Numbers/20	**Percentage**
Yes	17	85%
No	3	15%
Total	20	100%

Table 3.15: *Reusing emergency shelters by survivors (Research questionnaire)*



Purpose of reusing emergency shelters		
	Numbers / 3	**Percentage**
Store	5	30%
Mid-term sheltering	10	58%
Other purposes	2	12%
Total	17	100%

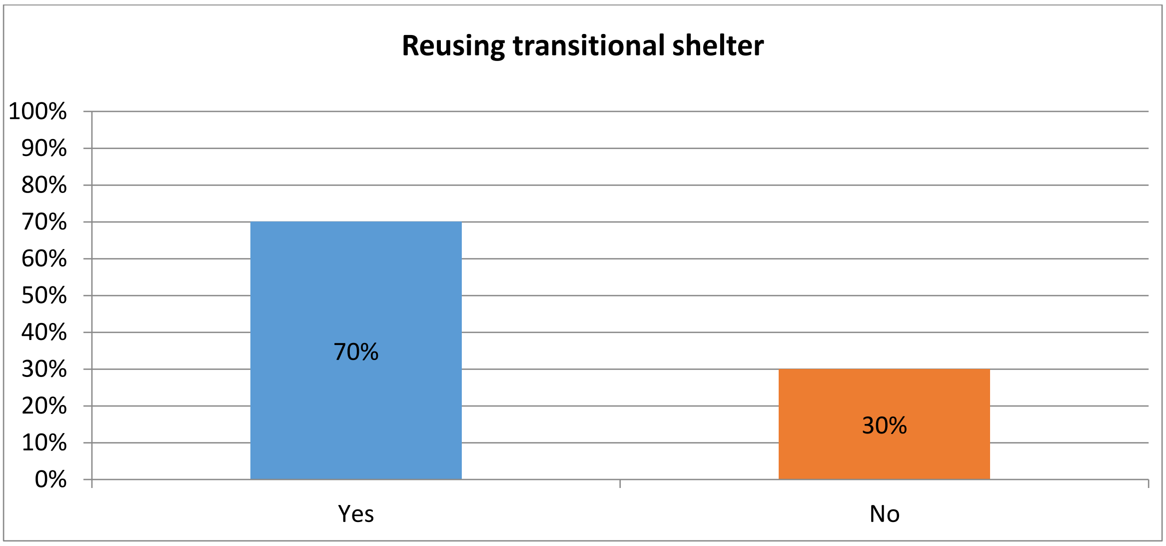
Table 3.16: *Reusing emergency shelters by survivors (Research questionnaire)*



Reusing transitional shelters by survivors		
Answer	**Numbers**	**Percentage**

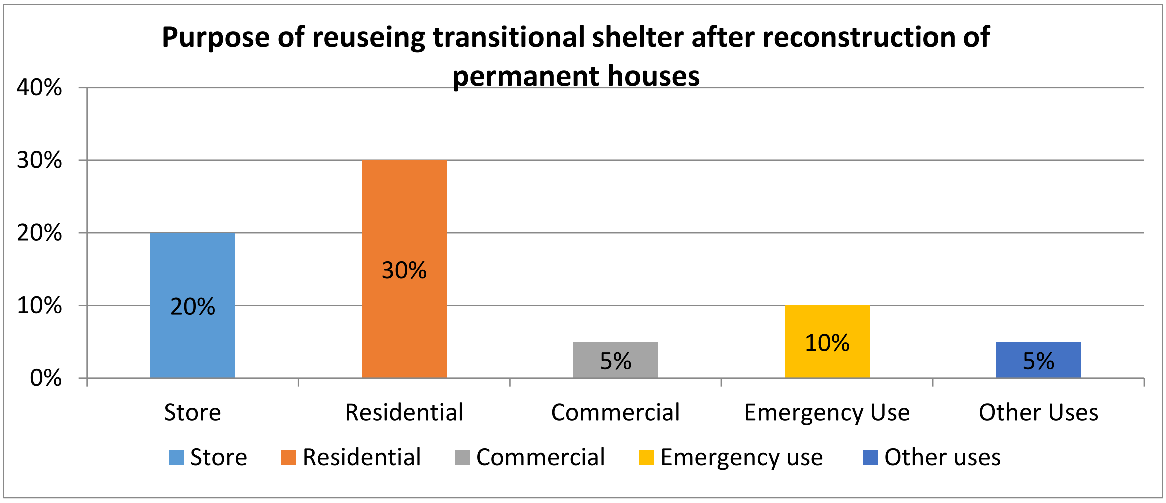
No	6	30%
Yes	14	70%
Total	20	100%

Table 3.17: *Reusing transitional shelters by survivors (Research questionnaire)*



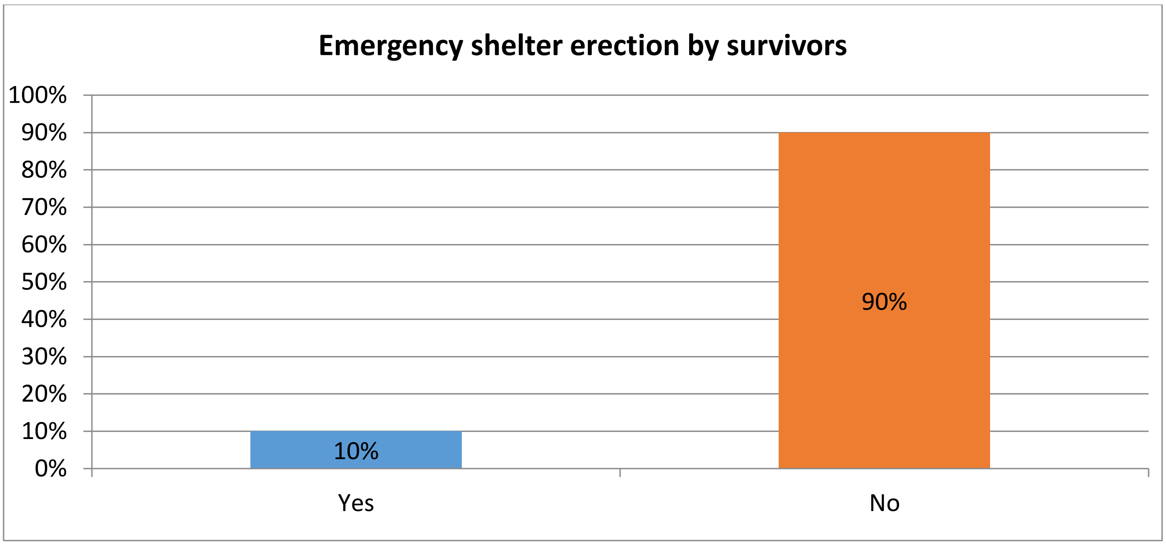
Purpose of reusing transitional shelter		
	Numbers/14	**Percentage**
Store	4	20%
Residential	6	30%
Commercial	1	5%
Emergency use	2	10%
Other uses	1	5%
Total	14	70%
Answered no	6	30%
Total	20	100%

Table 3.18: *Using transitional shelters for second time (Research questionnaire)*



Engaging with erection of emergency shelters		
Answer	**Numbers**	**Percentage**
Yes	2	10%
No	18	90%
Total	20	100%

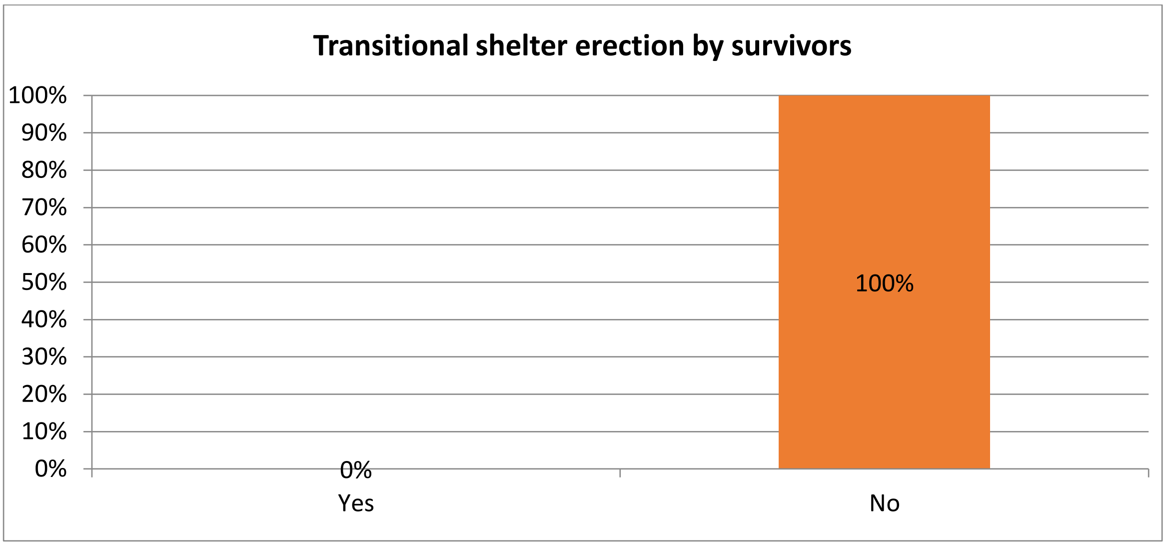
Table 3.19: *Engaging with erection of emergency shelters (Research questionnaire)*



Engaging with erection/ fabricating transitional shelters		
Answer	**Numbers**	**Percentage**
Yes	0	0%

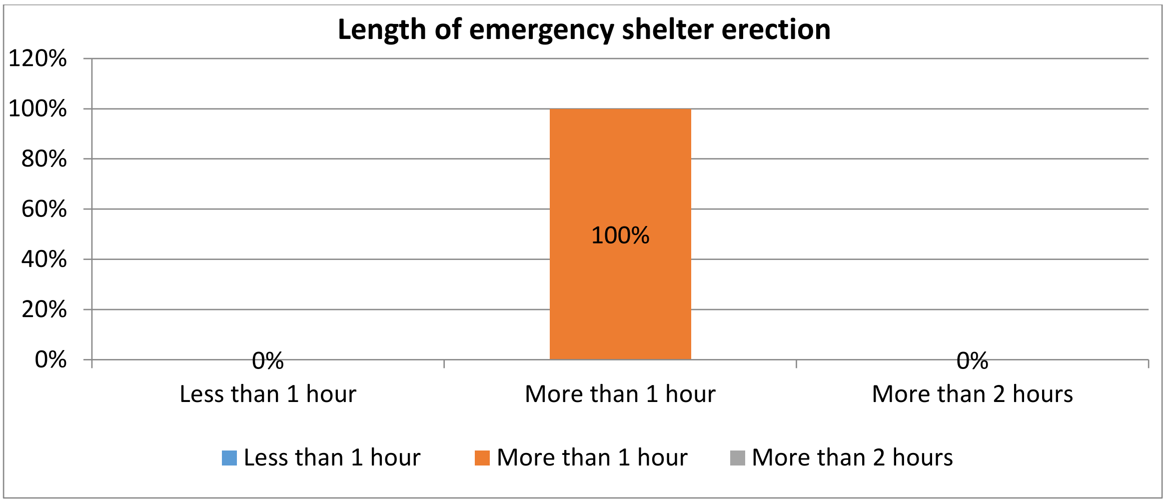
No	20	100%
Total	20	100%

Table 3.20: *Engaging with erection/ fabricating transitional shelters (Research questionnaire)*



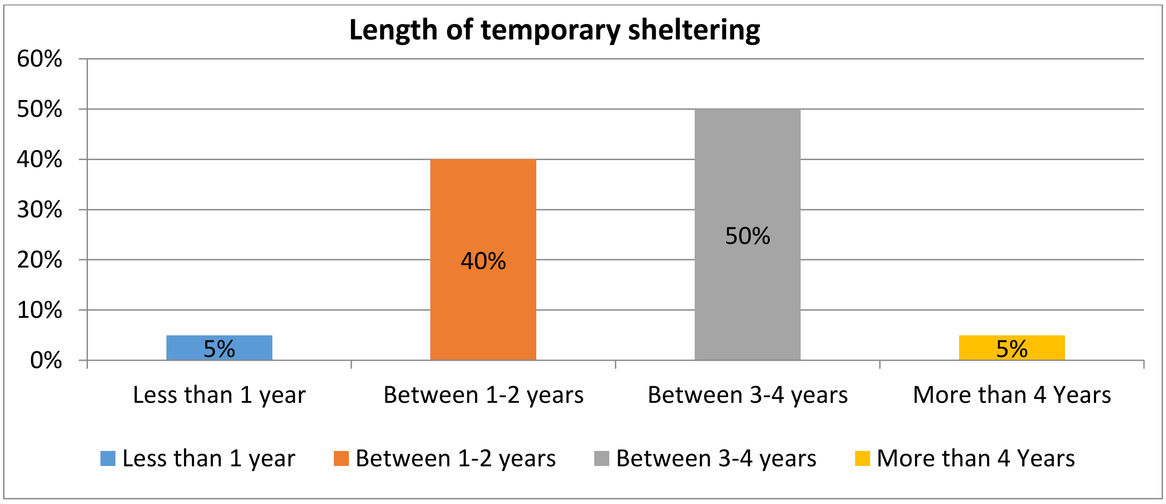
Length of erection of emergency shelters by survivors		
Answer	**Numbers/2**	**Percentage**
Less than 1 hour	0	0%
More than 1 hour	2	100%
More than 2 hours	0	0%
Total	2	100%

Table 3.21: *Length of erection of emergency shelters by survivors (Research questionnaire)*



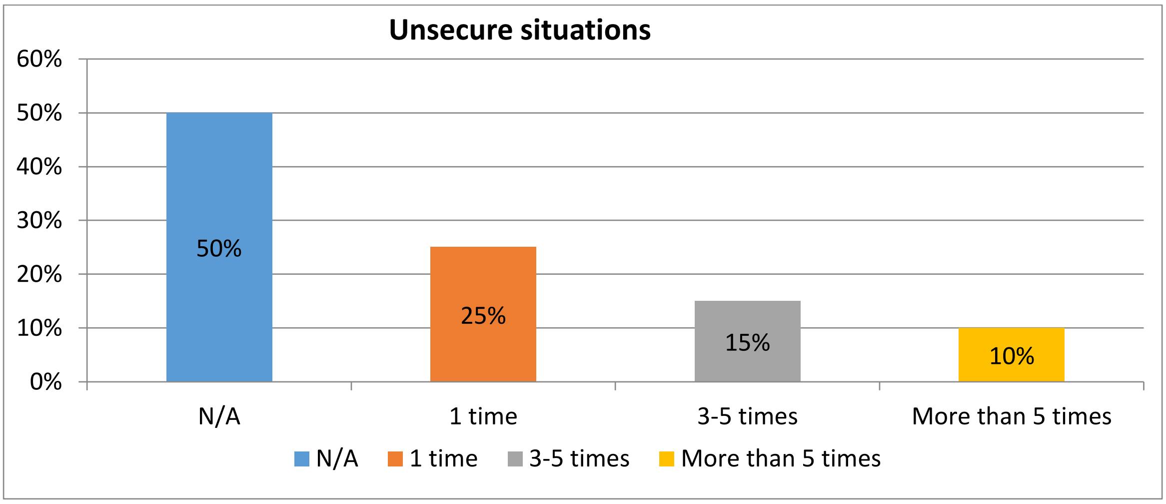
Total time of living in temporary shelters		
	Numbers/20	**Percentage**
Less than 1 year	1	5%
Between 1-2 years	8	40%
Between 3-4 years	10	50%
More than 4 years	1	5%
Total	20	100%

Table 3.22: *Total time of living in temporary shelters (Research questionnaire)*



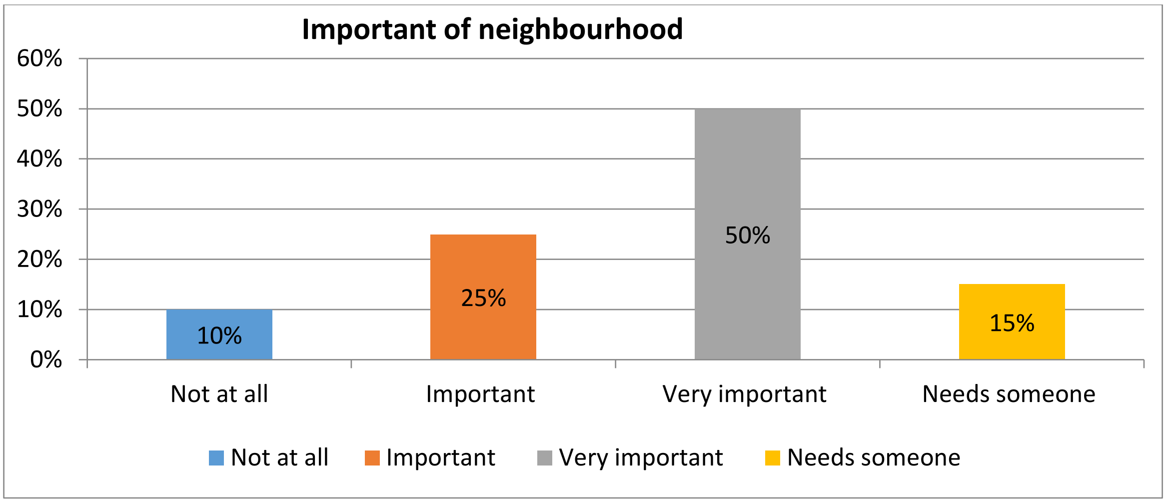
Number of unsecure or dangerous situations during temporary sheltering such as fire etc.		
	Numbers/20	**Percentage**
N/A	10	50%
1 time	5	25%
3-5 times	3	15%
More than 5 times	2	10%
Total	20	100%

Table 3.23: *Number of unsecure or dangerous situations during temporary sheltering (Research questionnaire)*



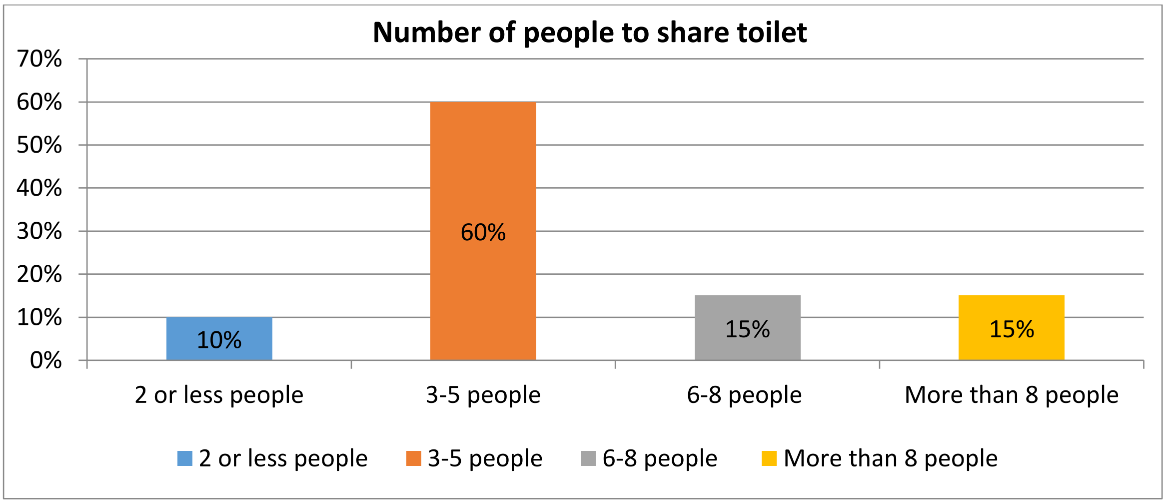
Importance of familiar people in your neighbourhood (Dependency)		
	Numbers/20	**Percentage**
Not at all	2	10%
Important	5	25%
Very important	10	50%
Needs someone	3	15%
Total	20	100%

Table 3.24: *Importance of familiar people in your neighbourhood (Research questionnaire)*



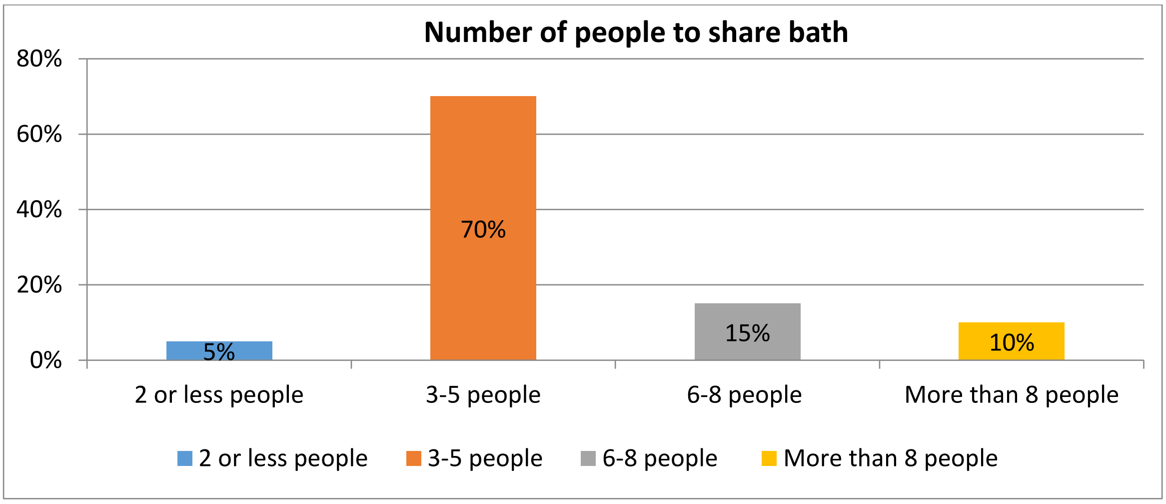
Number of people to share a toilet during temporary sheltering		
	Numbers/20	**Percentage**
2 or less people	2	10%
3-5 people	12	60%
6-8 people	3	15%
More than 8 people	3	15%
Total	20	100%

Table 3.25: *Number of people to share a toilet (Research questionnaire)*



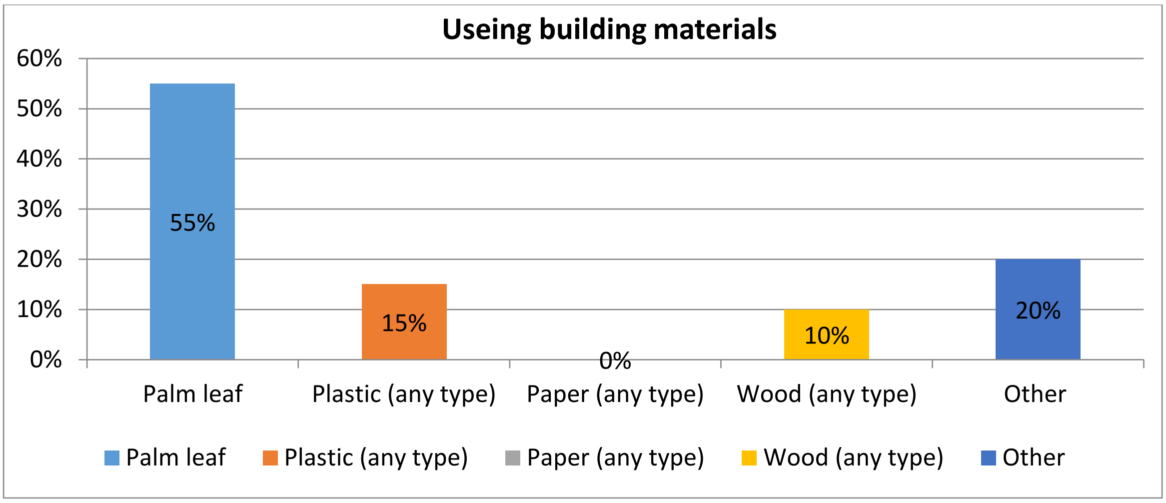
Number of people to share a bath during temporary sheltering		
	Numbers/20	**Percentage**
2 or less people	1	5%
3-5 people	14	70%
6-8 people	3	15%
More than 8 people	2	10%
Total	20	100%

Table 3.26: *Number of people who were using a bath during temporary sheltering (Research questionnaire)*



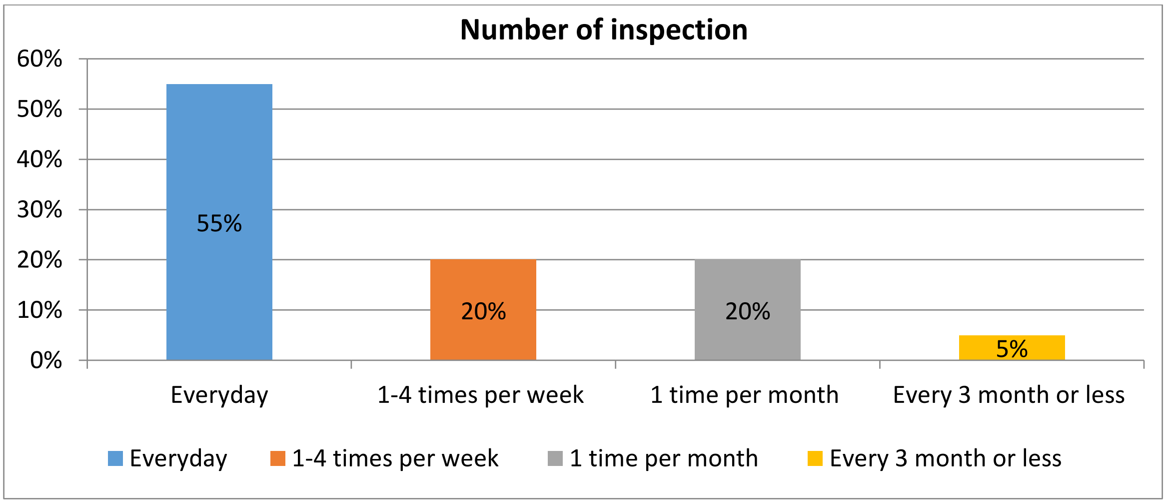
Experience of using any building material during temporary sheltering		
	Numbers/20	**Percentage**
Palm leaf	11	55%
Plastic (any type)	3	15%
Paper (any type)	0	0%
Wood (any type)	2	10%
Other	4	20%
Total	20	100%

Table 3.27: *Number of using any building material during temporary sheltering (Research questionnaire)*



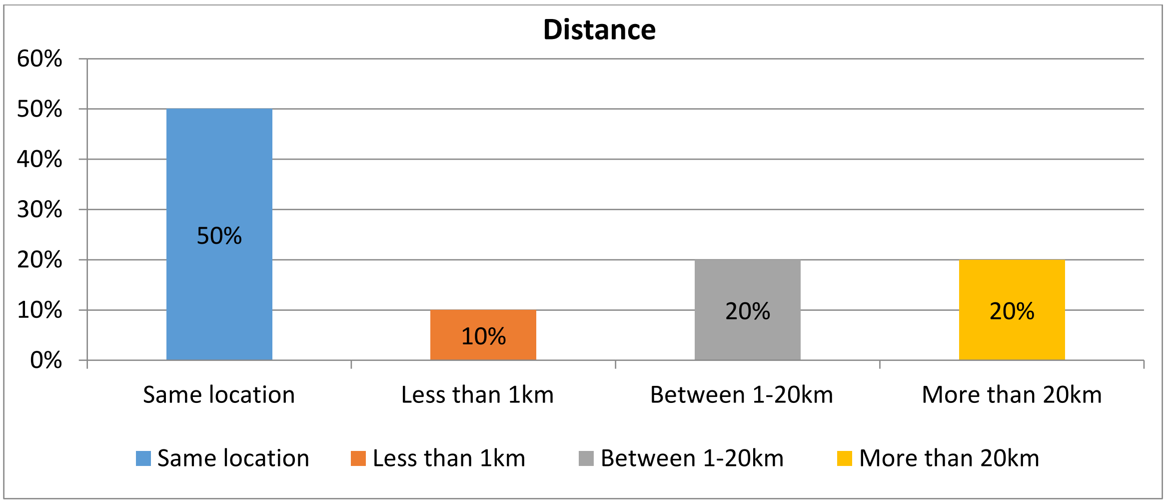
Number of inspections from your temporary shelter		
	Numbers/20	**Percentage**
Everyday	11	55%
1-4 times per week	4	20%
1 time per month	4	20%
Every 3 month or less	1	5%
Total	20	100%

Table 3.28: *Number of inspections from your temporary shelter (Research questionnaire)*



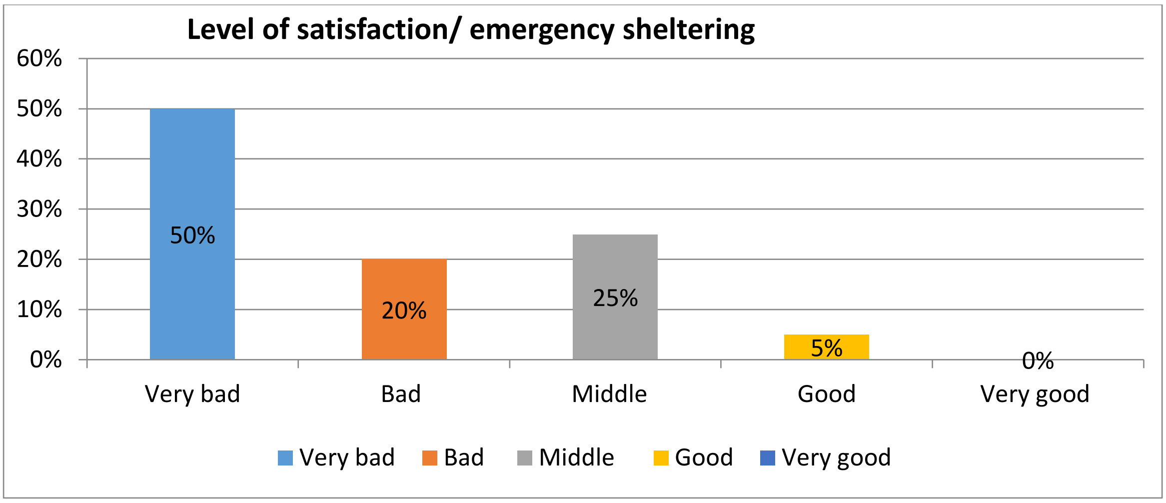
Distance between location of emergency and transitional sheltering		
	Numbers/20	**Percentage**
Same location	10	50%
Less than 1km	2	10%
Between 1-20km	4	20%
More than 20km	4	20%
Total	20	100%

Table 3.29: *Distance between location of emergency and transitional sheltering (Research questionnaire)*



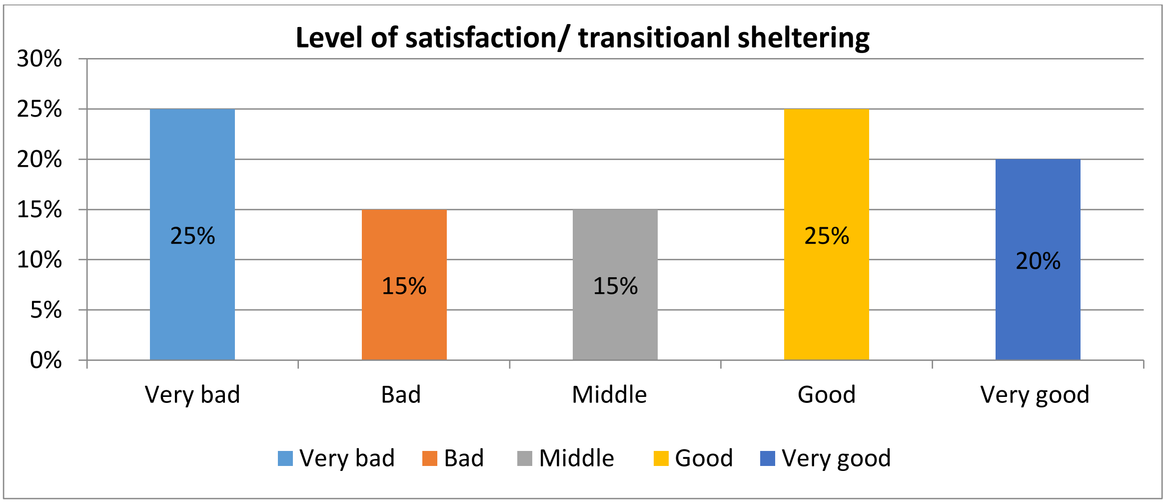
Level of satisfaction during emergency sheltering		
	Numbers/20	**Percentage**
Very bad	10	50%
Bad	4	20%
Middle	5	25%
Good	1	5%
Very good	0	0%
Total	20	100%

Table 3.30: *Level of satisfaction during emergency sheltering (Research questionnaire)*



Level of satisfaction during transitional sheltering		
	Numbers/20	**Percentage**
Very bad	5	25%
Bad	3	15%
Middle	3	15%
Good	5	25%
Very good	4	20%
Total	20	100%

Table 3.31: *Level of satisfaction during transitional sheltering (Research questionnaire)*



3.6 Conclusion

Temporary sheltering in Bam theoretically had to follow the national earthquake response cycle and leave everything to emergency NGOs but because of the complicated situation in the Bam earthquake, the depth of the disaster and the level of damages, the earthquake response cycle was delivered by a collaboration of central government, local authority, Iranian Red Crescent and the UN. The first strategy in temporary sheltering was not successful because of different reasons including;

- Firstly, because of inefficient management, planning and collaboration
- Secondly, ignoring the survivor's wish to stay in their private land and close to their collapsed buildings
- Thirdly, simple planning for camping with no prediction of access to natural resources and suitable topography.

Therefore, with the collaboration of Housing Foundation of Islamic Revolution, Ministry of Defence, Rashestan Architectural studio, Sahab Company, etc. 28075 units of temporary shelters were prepared. However, because of different reasons which mostly come from inefficient management such as not delivering the shelters on time or not preparing sites for transitional sheltering there were delays in delivering temporary shelters. Accordingly, these delays caused more problems such as attracting non-local people, social, cultural, health and safety problems. All of these reasons caused a change of strategy of planning from camps to survivor's private lands. Other reasons that caused a change to the strategy can be these reasons:

- Climatic conditions in Bam because of different types of gardens including palm gardens improves life conditions in hot and dry weather. Therefore, it was better to live in gardens in comparison with living in camps under sun heat.
- Economic dependency on palm trees in the survivor's house and gardens meant looking after these gardens are vitally important.
- Living in gardens help to avoid engaging with social and security issues in camps.
- Road access and connection to camps were too far and not in good condition
- Preference of survivors to be close to their collapsed building and valuable palm trees.
- Percentage of land per capita and building occupation in private lands is low.
- Percentage of ownership of residential buildings in Bam and Baravat are high.

Finally, the above organizations could deliver 9,050 units of temporary shelters for camps and 24,931 units of temporary shelters in survivor's private lands. Out of the delivered temporary shelters in camps 5,350 units were unoccupied and survivors preferred to avoid using them.

As expanded 20 survivors were questioned with designed questions in Chapter Two. Below is the summary of the findings.

15 survivors out of these 20 survivors were from Bam and 5 of them from Baravat. Generally, people who live in Bam in comparison with Baravat are in better economic situation. 60% of these survivors in Bam and 20% in Baravat preferred to live in their private lands. 14 years after earthquake, 27% of survivors in Bam left their city while this percentage in Baravat is 40%. One reason of this immigration is unemployment and second reason was bad quality of reconstruction in Baravat.

Both groups of survivors from Bam and Baravat had only one option for emergency sheltering and they experienced living in tents only. For mid-term sheltering they had two choices, to live in porta cabin or pre-fab cement unit.

These statistics show that 70% of these survivors were living in groups of four. It means that most of them were families, which had to live separate from each other, and 20% of them preferred to live with their families because as expanded dependency of families in Bam is in a high level and people look after each other.

Statistics show that 85% of survivors reused their tents after delivering transitional shelters such as porta cabin. Some of them reused their tents for mid-term sheltering in their private lands, some of them used it to store their personal belongings next to their transitional shelter and 12% used it for other purposes. This percentage in comparison with transitional shelter decreases. For instance, 70% of survivors reused their porta cabin. 20% of them reused it as store in their private lands, 30% to live as a part of their permanent house. 5%of survivors use their porta cabin as a shop. Comparison of these statistics shows that if quality of material is for sheltering is good, it can be used for other purposes for longer term.

Other statistics during fieldwork show that 90% of the survivors left emergency sheltering for emergency NGOs to erect their tent for them and 10% of them spent an hour or more than 1 hour to erected their tent by themselves. This number in transitional sheltering is 0%. This research proposes simplifying emergency shelter erection to accelerate disaster response cycle. As the result form of local traditional shelters in Kerman with local lightweight materials are proposed to design self-erection emergency shelter for survivors.

In total 50% of survivors lived in temporary shelters including emergency shelter and transitional shelter between 3-4 years and 40% lived between 1-2 years. Half of these survivors did not experience any dangerous or unsecure situation during their temporary sheltering such as fire, instability of shelter etc. This research considered to health and safety for midterm sheltering which is expanded in Chapter Six.

As expanded the level of social dependency in Bam is high and 50% of survivors marked it as a very important factor and 15% as completely dependent factor to live or close to friends, family or relatives. In shows that living in a separate tents was unpleasant for them in the Bam post-earthquake scenario.

In addition, as it was expected survivors during temporary sheltering were using different readily available material to cope with climatic conditions in Bam. As statistics show 55% of them used palm leaves for hot climate, 15% plastic sheets for rain and double glazing of their shelters. Mostly were using electric heaters for cold climate.

These statistics shows the depth of identified gaps in Bam post-earthquake scenario and next three chapters responds to these identified gaps including short/long term sustainability in emergency shelters, simplicity in erection of emergency shelters. Next three chapter discuss how this research responds to these gaps.

Chapter 4

Disaster response cycle in Bam

4.1 Introduction

This chapter is designed to provide answers to the subsidiary research question which is “What are the immediate architectural needs of people in natural disasters such as post-earthquake scenarios?” This chapter considers the earthquake response cycle day by day after the Bam earthquake to identify the immediate needs. In the next step, out of those immediate needs, all of the architectural needs are identified.

As considered in the Literature Review the response cycle consists of six stages including; relief, rehabilitation, landscape recovery, reconstruction, mitigation and preparedness. Majority of the immediate architectural needs refer to relief. An efficient response to a post-earthquake scenario includes: (Pelling, 2003);

- If required, evacuation of threatened people
- Emergency rescue of trapped or stranded people
- Administering first aid to the injured survivors
- Transportation of the injured or sick to hospital facilities
- Temporary sheltering
- Provision of food, water and other emergency items
- Immediate psychological support to survivors

All activities and requirements in relief can be counted as immediate needs for survivors and emergency NGOs respond to minimize damages. This chapter expands on different activities and requirements during relief in the Bam earthquake according to the daily basis responding to identify activities and requirements for activities. As expanded in the Bam fieldworks, temporary sheltering in Bam from beginning of emergency sheltering until end of transitional sheltering took seven months. (Fallahi, 2008) This chapter focuses on immediate architectural needs from the beginning of the earthquake in Bam till seven months after.

4.2 Earthquake response cycle

As discussed in the Literature Review, section Scales of the earthquake, the power of each level of the Richter scale was compared with an amount of TNT. In addition, effects of each level of the Richter scale on building was expanded. The table below shows that earthquakes less than 2 Richter do not cause any damage and no one feels any tremor but for earthquakes more than 3 on the Richter scale, emergency NGOs should respond urgently for any minor and major medical treatments in post-earthquake scenarios. Generally, the earthquake response cycle should be applied for earthquakes of more than 3 on the Richter scale.

Experience and statistics from Table 4.1 show that earthquakes on a scale between 3-5 Richter cause the shaking of objects inside the shelters but it does not cause any damage to buildings. Therefore, medical rehabilitation is a priority in earthquakes between 3 to 5 on the Richter scale. However, buildings with poor structures start collapsing with earthquakes at five or more on the Richter scale. Therefore, emergency NGOs should respond by delivering the full earthquake response cycle including delivering all activities and equipment for relief. This research designs a different range of emergency shelters for earthquakes with scales 5 to 10 Richter that are underlined in the table below. For this level of earthquake emergency shelters are required for different purposes. This research considers the earthquake response cycle in scales between 3 to 10 on the Richter scale and lessons learnt from previous experiences outlined below from the Bam earthquake.

Richter scale	1	2	3	4	5	6	7	8	9	10	11	12
Requirements			Medical response required		Emergency shelters required						Not reported through history	
Results			Shaking indoor objects		Building damage							

Table 4.1: Earthquakes and responses

1.6.8 Post-earthquake scenario

An interview has been conducted with Dr Alireza Fallahi[48] as an expert interviewee for this research on Tuesday 24/03/ 2015, Beheshti University, Tehran, Iran. He has been reconstruction leader of earthquakes in Iran including Bam earthquake. Therefore, he has experience of different post-earthquake scenarios with different economic, climate, geographical conditions in Iran with huge territory. Questions have been prepared in different fields.

Questions in terms of temporary sheltering are:

FB: What kind of temporary architecture would be necessary in a post-earthquake scenario? Are survived families going to cook, eat and sleep out of their temporary shelters? Can they do so inside of their temporary shelter?

AF: Climate of post-earthquake scenario is effective for sheltering. Generally, they affect more on long term temporary sheltering. However, it is not necessary to spend too much money for temporary sheltering in areas with moderate climate level in

[48] Dr Alireza Fallahi is Reconstruction leader in Beheshti University (National University), School of Architecture who has been leader of this course for ten years and has many experience in different earthquakes including reconstruction plan after Bam earthquake. In addition, he is a member of research committee of Iranian Red Crescent.

comparison with cold or hot climates. In these conditions survivors can stay in normal emergency shelters which are available everywhere. This type of emergency shelter does not need insulation material to cope with environment. In terms of cooking, eating, sleeping could be different because of different reasons such as economic conditions, cultural level but generally during living in emergency shelters warm food would be provided by emergency NGOs and during living in transitional sheltering as mid-term sheltering survivors can cook food themselves.

Long-term temporary settlement is more complicated in comparison with short-term emergency sheltering. Predicted strategy for temporary sheltering simplifies quick evaluation and decision making after an earthquake. These strategies and all decisions for sheltering have long-term effects of survivors and their lives. Temporary sheltering in camps might change physical borders and the structure of cities after an earthquake. Therefore, it has to be planned before as a strategy. An efficient strategy for emergency sheltering before an earthquake can reduce effects of quick evaluation and decision making after earthquake. Because of that, all of the emergency NGOs and other organizations that are engaged with earthquake should have a quick meeting for data sharing, quick evaluation and decision making.

Most of the decisions about the strategy of temporary sheltering can have an effect for long term. For example, if local authority or emergency NGOs spend and centralize the budget only in temporary sheltering, recovery and reconstruction would be delayed. Generally, time for temporary sheltering in a post-earthquake scenario takes more than predicted time and it can affect the form and shape of reconstruction that is happening around or close to crisis points. Basically, daily life happens in temporary sheltering and turns to normal life in long term through time. In fact in most of the countries there is no shelter and every shelter is the place for daily life and private territory. Some survivors prefer to stay there for longer term because of different reasons. Therefore, prediction of long term and short-term settlement in temporary sheltering is necessary.

FB: What should be the time management and priorities in temporary sheltering? How long would be needed for temporary sheltering? How long does it take to start permanent sheltering? Does temporary sheltering cause delay for permanent sheltering? If yes, how long for? What kind of temporary sheltering would be the best option to get permanent sheltering? Can camp preparation or temporary sheltering strategy before an earthquake simplify and fasten earthquake response.

AF: Before starting reconstruction strategy of permanent sheltering, local authorities or other relevant organizations should predict when permanent sheltering should be possible, for example to predict how long recovery or temporary sheltering with evaluating economic and other possibilities. Depending on scale of the earthquake and damages, permanent sheltering in in the areas with high level of damage can be reconstructed in one or two years, therefore short and long term temporary sheltering should be planned for this period. Temporary sheltering might includes preparation of cold climate emergency shelters, transitional shelters, prefabricated shelters, low cost shelters or settlement with family and friends. However if permanent sheltering takes more time, a different type of long term temporary sheltering should be applied. It should happen only through porta cabin, or prefabricated or wooden units that are efficient for long term temporary sheltering in a post-earthquake scenarios. Therefore, type of temporary sheltering depends on different situation of the site. In the Bam earthquake we evaluated site conditions and situation of affected people.

4.3 Description of the Bam post-earthquake scenario from the author's view:

The author during 2003 was an architecture student in Mashhad; the second biggest city in Iran. On Friday 26th December in the afternoon when he was going back home, he heard, from the radio in a taxi, that in the city of Bam (located in Kerman province) at 5:26 in the morning a big earthquake occurred. However, the statistics of human loss and economic loss were not clear for the government until late that night but in the morning of the following day, the TV broadcast that approximately 70% of houses were destroyed completely and the rest of the houses seriously damaged. At the same time, all media, broadcast that Mashhad Red Crescent was collecting goods and funds from people to transfer to Bam. Secondly, people who would like to help survivors as a volunteer could write their names in a waiting list. The author, with his cousin a medical doctor, turned up in the Red Crescent pavilion in the main square of Mashhad to write their names on the waiting list. Red Crescent were categorizing volunteers according to their skills. The author and his cousin realised that the Red Crescent did not need medical doctors anymore but the author received a call to be ready in 12 hours to be transferred to Bam for working in field kitchens and delivering warm food to survivors.

The following day, in the early morning, the author started his journey to Bam by a coach taking nearly 14 hours; which was approximately 5 hours more than usual time because of traffic congestions on the road to Bam. When all of the volunteers arrived at their camp out of Bam, it was realized that the emergency NGOs categorized volunteers into different groups such as trained volunteers, un-trained volunteers and international volunteers who mostly were highly trained with much equipment. International NGOs generally received better quality of services such as transportation, individual tents and armed police for their security.

The camp was very busy and it was located out of the city, very close to the border of the city. All volunteers on the first day of volunteering had a 30 minute training session about the conditions, the map of the city, available routes and other possibilities. In addition, all volunteers were asked to take all of their personal belongings because they might be asked to sleep in other camps in Bam in emergency shelters close to crisis points for easy access and quick response.

The author, with his group, was transferred to an elementary school that had not collapsed during the earthquake. He and his group were transferring goods, food and medical boxes to survivors who needed different things. At the same time, different emergency NGOs, under the control of local governmental organizations, were responding to survivors in different aspects. The rest of the experiences and observations will be explained in appropriate sections in different chapters.

However, two weeks after the earthquake it was declared that approximately 43,000 people were killed, over 20,000 people injured and 60,000 people became homeless. National earthquake information stated that the centre of the earthquake was exactly southwest of the city of Bam and the scale of the earthquake was 6.5 in magnitude. In that earthquake, approximately 70% of houses were destroyed completely and the ancient 2,000 years old citadel was seriously damaged (Ramazi and Jigheh, 2006).

The Bam earthquake, which was one of the biggest earthquakes ever in Iran is an efficient reference for this research for different reasons. Firstly, it required national and international, individual and collective actions. Secondly, the author has his personal experience in the Bam earthquake coping with different issues such as different lifestyle, climatic conditions etc. Thirdly, the special historical site conditions caused many restrictions in the earthquake response cycle.

All the humanitarian responses in this case study, including architectural and non-architectural responses, were affected by the UNESCO historical site. The author experienced that after the earthquake all transportation options were limited to a few options and specific routes only. For instance, helicopters and airplanes landed at some distance in the city of Kerman to reduce further damage to Bam citadel and they were transferring all of the deliveries by trucks to three Red Crescent base points around Bam. Finally, volunteers were responsible to deliver different needs from these base points including stores, car parks, fuel stations, field kitchen and field hospitals to survivors tents that were in different camps in the city or close to collapsed houses. The author two weeks after Bam earthquake was responsible for delivering warm foods from the field kitchen to emergency shelters in person.

4.4 Daily activity and requirements after the Bam earthquake

This part expands on and lists all of the activities and requirements of the Bam post-earthquake scenario accurately after the earthquake on a daily basis to analyse the immediate needs in different periods.

4.4.1 First day of the Bam earthquake

In terms of survivor’s immediate needs, it should be mentioned that most of their immediate needs appears at once and it is vitally important to respond during the first to third day of post-earthquake times. However, some of those short-time term immediate needs are required for the first few hours or few times such as minor medical treatment and some of those immediate needs are required for longer term such as access to healthy and safe water resources. Alternatively, access to temporary shelters during the earthquake response cycle is required all the time.

The United Nations, one day after the Bam earthquake provided an initial report of the Bam earthquake in report No 845 made by the humanitarian section of United Nations as below[49]:

- 26th December 2003, in 5:26 AM in local time an earthquake occurred at 6.5 on the Richter scale.
- 60% of buildings collapsed
- Bam hospital collapsed, landline and mobile phones were disconnected, water and electricity suppliers stopped working.
- Rescuing trapped people was started by local authority, Iranian Red Crescent and army.

The Iranian National Crisis Management Organization is an organization of the Ministry of Interior of the Republic of Iran and is based in Tehran. This organization, with the high level of damage in initial reports from Kerman Red Crescent, realized that local emergency organizations are out of service and the level of response required a national scale and international scale rather than local or province scale. Therefore, this organization, as the central command, formed two separate groups of responders in the Bam earthquake scenario. One group was required for quickly responding to the people of Bam for the emergency rescue of trapped people and administering first aid to the injured people. The second group was to manage the site and international responses. The first group was a mixture of national and international NGOs but the second group was only under the control of national organizations. (Fayazi, 2011)

As in other earthquake responses, emergency NGOs started with emergency actions and equipment to save people. Important instructions for the first 24 hours to the third day in Bam were as below. It is important to mention that the majority of the immediate needs of survivors appear and are required in this step.

- **Purification of water in Bam:** Considering the scale of responses from the Literature Review, one action before earthquakes is the preparation of equipment for water purification. After the Bam earthquake water infrastructure was damaged. Therefore, there was no access to drinking water after the earthquake. Only a few underground and over-ground water resources were available and survivors did not have easy access to those resources. Therefore, emergency NGOs had to purify and transfer different water tanks for people in different points of camps and city (Fayazi, 2011).

[49] http://www.unicef.org/iran/BAM_EVALUATION_FINAL-_FINAL.pdf

- **Providing toilets:** Toilets were one of important required spaces after the earthquake because with collapsing building or serious damages to buildings, providing mobile toilets were necessary for health and safety. For this reason, emergency NGOs provided boxes of toilets that should be located inside cubic tents. With reference to the section structure of emergency sheltering in the Literature Review standards in Bam were; in a unit of emergency shelter for a family of four the standard is a minimum 12 square metres. The number for a transitional shelter is 24 square metres. A tent of 12 square metres as an emergency shelter with a separate toilet should be located in a field of 100 square metres (Fayazi, 2011).

Figure 4.1: *Emergency drinking water tanks and emergency toilet tents during emergency sheltering in the Bam earthquake (Abadi, 2004).*

Figure 4.2: *Transitional toilet/bath unit (Ref: www.mojepishro.net Access date: 25/06/2015)*

- **Waste disposal or recycling:** Disposing or recycling waste materials is another important issue in a post-earthquake scenario. However, this issue is not an immediate architectural need and it does not require any shelter for waste disposal or recycling inside the post-earthquake scenario.

- **Spraying the site with disinfectant:** After Bam earthquake, because of the collapsing buildings with some dead bodies, dead animals and rotting vegetables buried under building materials, diseases such as Cholera appeared in Bam. Therefore spraying the earthquake site with disinfectant was necessary. The author and other volunteers who were dealing with field kitchens and survivors were strongly recommended to use a mask in every location.

- **Registering injured survivors through placards, inspection on transferring injured survivors to field hospitals and finally registering dead bodies with photography:** Any medical response for short term or long-term treatment requires hospital facilities. In the Bam earthquake, hospitals were damaged and were out of service. Therefore, providing field hospitals and mobile clinics were vitally important. As the figures 4.3 show during the first to third days of the Bam earthquake national organizations including the Iranian Red Crescent, provided a number of different tents as mobile field clinics and field hospitals for any minor and major medical treatments. However, other international NGOs provided a number of different field hospitals that are expanded in this section.

Figure 4.3: *Minor medical treatment from field clinics (left), field hospital for major medical treatments (right), (Ref: ISNA News Agency: Access date: 27.06.2013)*

- **Providing a covered bin station and trucks for transferring bins out of cities:** Bins in a post-earthquake scenarios can be a source of disease. Therefore, management and transferring bins from the beginning of disaster is vitally important. During the Bam earthquake, because of the number of different volunteers, collection of bins was in person every 1 hour to transfer it to a truck out of the city. Therefore, the author during volunteering did not see any bin station but he met a lot of volunteers who were responsible for transferring bins from survivor’s tents. However, for the collection of specific types of bins such as hospitals, toilets and kitchens specific types of trucks or tankers were planned. After a week different recycling and bin stations were provided by emergency NGOs.

- **Looking after children physically and psychologically:** Children in a post-earthquake scenario are one the groups that need special care. Any physical or psychological damage to children causes long-term social problems. One day after the Bam earthquake national NGOs opened one nursery in a camp in Bam and one in Baravat for those children who had lost their parents. Through time, international NGOs opened more nurseries because the Iranian Red Crescent nursery was full and they planned a different number of nurseries in other part of the Bam. Therefore, a nursery facility was another immediate required space after the Bam earthquake.

Figure 4.4: *Iranian Red Crescent erects a number of tents as nurseries in Bam and Baravat (Ref: Left by author, Right: www.mojepishro.net, Access date:25/06/2015)*

- **Securing the post-earthquake scenario against theft**: as it has been expanded in the Literature Review before, security in every society is one of the fundamental human rights. This issue in post-earthquake times because of the special conditions becomes more important and is one of the immediate needs. In Bam the population of people after the earthquake was more than before the earthquake. As expanded before, this was because of different reasons such as attendance of family, friends, relatives, volunteers. However, some people from inside the country and some people from neighbouring countries moved to Bam to rob the personal belongings of survivors.

- **Using trained dogs or other high-tech devices to find and rescue trapped people:** This activity is another immediate need during the first day to the third day of the earthquake to minimise human losses. During the Bam earthquake the Iranian Red Crescent did not have any trained dogs or other high tech devices to rescue trapped people. After the Bam earthquake, the Red Crescent opened different dog training centres. In this period, it is one of the immediate needs.

The United Nations Humanitarian and Disaster Relief Assistance sent a group to evaluate needs, damages and responses to survivors. This organization donated 90,000 US dollars on the first day of the Bam earthquake.

Finally, emergency needs, from the beginning of earthquake to the third day of the earthquake, are for different activities such as appropriate shelter but some survivors do not need this. These needs are medical treatment and medical aid, emergency shelters for survivors, field hospitals, blankets, electricity generators, water purification equipment, rescue and emergency teams/trained dogs to find trapped people. Out of all immediate needs in this stage of the earthquake response cycle, only shelter for survivors, field hospitals, field clinics, nurseries and toilets are immediate architectural needs from the beginning to third day of the earthquake and national/ international NGOs using the same type of tents.

4.4.2 Three days after the Bam earthquake

Public announcement number 848 from the United Nation Humanitarian and Disaster Relief Assistance, based in New York on 29th December 2003 declares that (OCHA, 2010):

On third day of the Bam earthquake UN crisis evaluation group with collaboration of the British Red Cross did an air evaluation with an Iranian army helicopter. This group covered all five zones and 22 districts in Bam and documented all of the damages. Separate damage evaluation should be conducted for 15 villages around the city of Bam.

As expanded in the section, Bam after the earthquake, a big part of Bam had been damaged, specifically the ancient Bam citadel and buildings around Bam's central football pitch were seriously damaged because the main material of these buildings were mud brick, clay and wooden structure. Most of the public buildings, including two hospitals and schools were seriously damaged. Survivors around these areas by the third day of the response were less than 10%.

There was no accurate statistic but statistics from the local authority shows that until the third day of the response 20,000 people were killed and they predicted this number would rise to 30,000. A further 30,000 people were injured and 70,000 people became homeless, so most of these people, because of lack of management in providing emergency shelters, were transferred to other cities and villages to live with their families, friends and relatives for sheltering and psychological support. The rest of the survivors who stayed in Bam, because of different aftershocks, avoided living in public buildings that had not collapsed, they preferred to live in outdoor spaces. Those buildings that did not collapse were being used as a crisis points such as Bam high school for girls that was seriously damaged (Fayazi, 2011).

By the third day, a huge number of tents were delivered to Bam but there were not enough numbers of trained volunteers to erect the tents for survivors. Therefore, the Iranian Red Crescent asked international NGOs to erect them and prepare immediate architectural needs but asked Iranian NGOs/trained volunteers to start training survivors how to erect their own emergency shelters in camps or their own private gardens. As the image below (Figure 4.5) shows the Iranian Red Crescent were training survivors in two groups of men and women after the earthquake.

Figure 4.5: *Training survivors after Bam earthquake how to erect their tents (Ref:www.helalemehr.blogfa.com Access date: 25/06/2015)*

As expanded in this period, emergency NGOs were engaged with various issues. On the third day of the Bam earthquake, with many national and international volunteers and folded tents, which had been delivered to Bam, they were not able to respond to all of the immediate architectural needs. Emergency shelters were delivered to survivors but there was no emergency responder or trained volunteers to erect those shelters for them. More of the trained volunteers were busy with preparation of field hospitals, clinics and large scale emergency shelters.

Figure 4.6: *Emergency NGOs erecting large-scale tents in the Bam post-earthquake scenario, Amir Camp (By author)*

This research because of this experience as a development, designed different ranges of self-construction emergency shelters that are based on familiar local forms, materials from Kerman and simple erection mechanisms for non specialists. Through this approach, this thesis maximises public engagement in shelter erection. Therefore, emergency NGOs do not need to send any trained volunteers with their emergency shelters.

Water and electricity suppliers provided temporary power and water equipment through different methods. At the same time, they started reconstruction of the damaged infrastructure. While emergency NGOs were delivering different services, demands for mid-term needs and long-term needs were increasing, there was additional air traffic for Kerman airport as a centre of the province and some flights were diverted to other airports. 1,345 people in 34 international rescue and emergency care teams from 28 countries and 20,000 Iranian volunteers were in the post-earthquake scenario for responding. (Abadi, 2004)

4.4.3 Five days after the Bam earthquake

Public announcement number 849 from the United Nation Humanitarian and Disaster Relief Assistance, based in New York, on 31st December 2003 reports that:

International responses to Bam from responding to short-term needs such as rescuing and emergency aid from the fifth day of the earthquake were changing to mid-term responses. From 30th December 10 rescue groups left Bam but medical aid still was continuing and the role of medical aid was becoming more important. Demand for emergency shelters for survivors as shelter and field hospitals were increasing. Statistics are provided below (OCHA, 2010).

During the first five days after the earthquake, 1,400 flights had been landed to deliver national and international responses. Out of different requirements in the first five days the priority and most important requirements was medical responses and emergency shelters for survivors. There was enough water and food in Bam for survivors and volunteers. Different tents, blankets and heaters were delivered daily to Bam that volunteers were responsible for loading, unloading and delivering straightaway to survivors. [50]

The United Nations delivered 1,000 tents, 10,000 blankets and 3,000 mattresses to Kerman airport during 5 days (OCHA, 2010) but as training sessions for survivors in post-earthquake time shows, preparation of emergency sheltering is too slow and needs trained volunteers or survivor engagement.

UNICEF sent many first aid packages, blankets, water purification tablets, water tanks, diesel generators to produce electricity, tents and ropes. UNICEF started supporting educational support with 400 educational packages. Each package had educational material for 80 students and some equipment for teaching. In addition, 10,000 set of children clothes including coats, trousers, boots, shirts, socks and gloves were provided in Tehran to deliver to Bam.[51] These statistics show the importance of the psychological support of children. As expanded before, any serious psychological damage to children causes long-term social problems, therefore, nurseries can be counted as another immediate need that requires a shelter.

In first five days, the Iranian Red Crescent organized short-term medical treatment for 30,000 people and transferred 10,000 people to seven big cities for long-term treatment. They organized five international field hospitals by the fifth day after the

[50] Aftab Yard Newspaper on Saturday 10/04/2004

[51] http://www.unicef.org/iran/BAM_EVALUATION_FINAL-_FINAL.pdf

earthquake and another five field hospitals would start working from the sixth day after the earthquake. In total 12 field hospitals were planned for the medical responses. (Fayazi, 2011). Still five days after the Bam earthquake most of the NGOs were busy with the preparation of field hospitals. Erection of field clinic tents, because of the small size of tents, were prepared quickly but field hospitals because of the large size of the tent needed more time to erect and more equipment.

However, some special units such as surgery units were delivered as a porta cabin because installation of equipment in surgery rooms takes a long time and all of the equipment and environment should be sterilized. The image 4.7 below shows a transitional surgery unit in a post-earthquake time. In addition, a different range of emergency shelters are presented in the portfolio in this research. These prototypes are foldable and erectable therefore it is not possible to store any equipment inside.

Figure 4.7: *A transitional surgery unit in post-earthquake time in a porta cabin (Ref: http:ostan-as.gov.ir Access Date: 25/06/2015)*

The number of survivors was not clear because approximately between 20,000 to 30,000 of survivors left Bam to live with their family, friends and relatives who lived out of Bam for further support. At the end of the fifth day of the earthquake, 28,000 deaths were registered and they predicted this number to rise to 34,000 during the next 24 hours. (Fayazi, 2011) Therefore, the Iranian Red Crescent divided Bam into 22 sections and started registering survivors for mid-term sheltering. They started the identification of indoor and outdoor spaces that had the potential to be crisis points to accommodate 40,000 people. As expanded in the Literature Review section delivering temporary shelters, some private architectural studios such as Arman-Shahr Company that is based in Tehran, identified empty land that had the potential to be camp sites. The Red Crescent with collaboration of the local authority started constructing camps.

There is a report about psychological and mental health conditions of survivors on the seventh day of earthquake from Tehran University[52] that this not related to temporary sheltering and emergency sheltering. However, Tehran University on the seventh day provided a tent for psychological consultations for survivors who were in need but because of huge number of appointments, they increased the number of consultation points in different parts of Bam. The most important concerns of this report was depression of survivors and security during night times when some people started looting other people properties which caused stress and feeling of insecurity, even between volunteers (Fallahi, 2008). Experts from the Tehran University with the collaboration of emergency NGOs required security forces, medical collaboration and appropriate spaces. The Iranian Red Crescent prepared tents as consultation rooms but because of the huge number of survivors, it was not possible to provide a large-scale tent because its erection needed a crane and special equipment. Therefore, they used a different number of smaller sizes of tent separately.

Figure 4.8: *Psychological consultation tents for men and women in Bam (Ref: http:shastoon.ir; Access date: 25/06/2015)*

4.4.4 Ten days after the Bam earthquake

A report from French Field-hospital (Doctors without Borders) on 6th January 2004 shows that [53] :

[52] Saravan News Agency; *http:ostan-as.gov.ir Access Date: 25/06/2015*

[53] Iranian Emergency Medical Response society: http://www.emairan.ir/fa/ Access Date 18/06/2015

Ten days after the earthquake there are new issues appearing in the post-earthquake scenario. The official number of deaths is approximately 40,000 and approximately 40,000 people have survived.

The local authority prepared camps to transfer survivors from tents as emergency shelter to mid-term shelters because emergency NGOs planned to remove tents to start landscape recovery and reconstruction. However, some survivors insisted on staying close to their collapsed buildings. Landscape recovery would be more difficult with these survivors.

By the tenth day after the earthquake emergency NGOs provided an extra 15,000 tents and 1,000 porta cabins more than they expected for people who moved to Bam such as families, friends or volunteers. Ten hospitals out of 12 were responding to medical needs.

There are similar reports from an American field hospital[54] and an Indian Army field hospital in the Bam post-earthquake scenario that mentioned their medical activities and their medical equipment in their field hospitals.

Figure 4.9: *Indian Army field hospital in linear plan and large size in comparison with other tents. (Ref: Mehr News Agency, Image Credit: Younes Khani)*

As this daily report shows still after ten days immediate architectural needs are not responded to completely as planned and emergency NGOs with extra temporary shelters in Bam were still erecting and responding to the immediate architectural needs.

[54] New England Journal of Medicine in 18th March, 2004

4.4.5 Eleven days after the Bam earthquake

As mentioned before, needs in the Bam post-earthquake scenario were changing from short-term and emergency needs to mid-term after five days. From this part, this research tries to focus only on the sheltering process during the days after the earthquake because with the increasing length of stay in the post-earthquake scenario the number of requirements increase too. The reports for the eleventh day of the earthquake come from the report number 12 by the United Nations in Geneva on 6th January 2004.[55]

The number of injured people until the eleventh day was 30,000 people of whom 10,000 people were transferred to other cities straight away and 20,000 of them had short or long treatments in Bam field hospitals.

The number of survivors who needed emergency shelters were approximately 45,000 people but with the return of injured people who had been transferred for medical treatments before, the number of people who needed shelter might increase. In addition, there was the possibility of families, friends and relatives of survivors coming to Bam to offer support.

In total, from the first day until the eleventh day after the earthquake, 8.3 US million dollars in different formats including fund and goods had been donated. Out of 29,500 permanent shelters, approximately 25,000 houses and public buildings were 85% damaged (Fayazi, 2011). This number shows the scale of immediate architectural responses and volunteers required to respond to this need to erect temporary shelters.

The Iranian Red Crescent was one of the leaders of the post-earthquake management in Bam. An important point is; the building of Bam Red Crescent was seriously damaged but rescue teams from Kerman and Tehran started responding quickly and efficiently. The Iranian Red Crescent with the support and collaboration of the Army and international NGOs finished responding to immediate needs and started responding to mid-term needs of survivors.

4.4.6 Seventy-six days after the Bam earthquake

A member of the Iran Urban Social Science Council, based in the Housing Ministry in Tehran had an inspection seventy-six days after the Bam earthquake. Below are some outputs of their report related to temporary sheltering.

Emergency sheltering started by providing tents and approximately 30,000 tent were delivered to survivors to live in open spaces with some living close to collapsed houses. The process of emergency sheltering, because of the lack of trained volunteers, was too slow. The first 72 hours of rescuing trapped people is very important but the rescue team engaged with emergency sheltering too during those hours as well. Long term temporary sheltering was started after delivering all predicted number of temporary shelters to the post-earthquake scenario (Asadi, 2007).

[55] Iran's official news agency: http://www.irna.ir/fa/News/80863195; Access Date 19/06/2015

Most of the survivors, transferred their saved personal belongings to their tents. Some of those survivors who saved more personal belongings had less room inside of their tents therefore they left their belongings outside of their tent, which is the reason for insecurity and theft in the Bam post-earthquake scenario. Generally, people of Bam, because of their lifestyle, were living in garden houses that consisted of a land and a building. Every family has a lot of house furniture, kitchen materials and personal belongings. Bam survivors, which are expanded upon in Literature Review, needed more rooms inside the shelter to keep their personal belongings. This research through designing a modular emergency shelter units that has the possibility of extension and attaching to another units develops emergency sheltering. Different range of prototypes in the portfolio present the mechanism of erection and connection methods of designed units. Through these methods, survivors are able to expand and extend their shelter as much as they need to save their personal belongings. In addition, with increasing storage space inside the tent, security would be improved.

Figure 4.10: *Survivors because of small size of tents had to keep their personal belongings out of their tents (Ref: Mehr News Agency, Image Credit: Younes Khani)*

Access to the shower, toilet and places for washing dishes and laundry were not in a good condition during the first 20 days because predicted number of facilities such as toilets, showers were not enough, but access to toilets and showers during mid-term sheltering were in a good condition. Furthermore, because of the climatic conditions during the hot daytime and cold weather during night times and living in tents for more than the expected time, the risk of disease was high. Therefore transferring survivors from their tents to a porta cabin was a priority by this day (Asadi, 2007).

The Defence Ministry made an un-professional decision on the day of the earthquake to start constructing 20,000 porta cabins for 28 points of Bam without initial site analysis. The price of each porta cabin unit was £900 and they spent over 18 million pounds after the Bam earthquake. Experienced people who were engaged in the reconstruction of cities after the eight years imposed war from Iraq, recommended to avoid this quick decision because it would have long-term effects on survivors' lives (Fallahi, 2008).

As expanded in the Literature Review, survivors were not happy to have their porta cabin in camps. They preferred to have their shelter in their private land and properties but it caused more time for landscape recovery and flattening their lands after collapsing their permanent shelters. Statistics show during seventy-six days only 15% to 30% of waste building materials removals had been done. The Red Crescent estimated approximately 30 million M^3 of waste building materials should be removed from Bam (Fallahi, 2008). With the Bam earthquake, the economy of the city is damaged seriously too. Except for orange and date gardens, the rest of the businesses, including buildings for packing agricultural products and trade centres, central Bazar, factories around city had collapsed. The most serious economic damage was due to tourism industry. The ancient Bam Citadel was a tourist attraction on a world scale, which was seriously damaged during the earthquake (OCHA, 2010). The demolition of collapsed buildings and waste building material removal were the conditions of mid-term sheltering in survivor's private lands. Therefore, the local authority formed a waiting list and registration process with property documents.

Recycling of waste materials is an important issue. Survivors and property owners knew before removing waste building materials from their properties, they had the chance to recycle building materials by hand between waste materials. These secondary material options have the potential to be applied for upgrading emergency shelters for mid-term sheltering. These material options are expanded in Chapter Six Material design. For instance, survivors during landscape recovery, were keeping wooden posts and beams for reusing during the reconstruction of their permanent shelters.

As discussed in section 1.7.5 in the Literature Review, the city of Bam is 27 square kilometres and there are 18,000 residential and commercial buildings. Approximately 85% of these buildings had collapsed. (Fayazi, 2011) Therefore, a big part of the city needed landscape recovery. This approach to the amount of waste building materials can be reused for upgrading emergency shelters for mid-term sheltering. The majority of people who survived the earthquake started, during that time, to collect useful materials for permanent sheltering (Figure 6.10). This research uses these materials for upgrading emergency shelters. It can be one of the most sustainable methods of temporary sheltering. This approach is discussed in Chapter Six, Material Design.

By this date different mid-term and long-term architectural needs appear in the post-earthquake scenario. For instance, some survivors need another temporary shelter such as a store or shop. The figure 4.11 shows different porta cabins were used as different shops such as a butchers, bakery, pharmacy. The problem was all survivors or other people who were in Bam after the earthquake had to wait for a very long time for a porta cabin or other types of temporary shelters to present their agricultural or other types of products.

***Figure 4.11:** Temporary shelters as a butchery and pharmacy in the Bam post-earthquake scenario (Ref: by author)*

4.4.7 Report of an architect from Bam after earthquake

Dr Cyrus Majid-Zadeh a professor in Azad University of Mashhad where he teaches environmental design, was invited to Bam three months after the Bam earthquake by the Home Ministry for an inspection. The author had an interview with him in Mashhad on Monday 6th April 2015 in Azad University of Mashhad about the Bam earthquake in Persian language. Below are some questions and answers:

FB: Dr Cyrus Majid-Zadeh when you think about the Bam earthquake what do you remember about the process of sheltering and temporary shelters?

CM: The Earthquake in the city of Bam had been more destructive than villages around Bam. More than 85% of the city has been damaged. The Bam earthquake occurred 41 years after Buin-Zahra earthquake and 13 years after Roudbar earthquake. Only 15% of Iranians live in earthquake resistant buildings. Public buildings that are collapsed or damaged seriously are the city council, which was supposed to be crisis management centre, Bam fire station, different banks, civil justice court that is collapsed completely, new Bam hospital that was constructed less than ten years ago, Bam airport including control tower and hall of residence for students. The interesting point is: generally old building of Bam such as old Bam hospital, schools and mosques were damaged less in comparison with new constructed public buildings. The Local authority closed Bam citadel as a UNICEF world registered heritage site. The collapsing new buildings in Bam is a sign of weakness in building industry in recent decades.

FB: Dr Majid-Zadeh, I know it is not a good condition, but what were people thinking about their shelter? Were people satisfied about their shelter?

CM: Meeting with some survivors who were living in emergency shelters shows that, firstly, delivered goods to their tents do not match with their actual requirements and emergency NGOs do not deliver their actual requirements. Some of them had to erect their own shelter after medical treatments and it took a long time to erect their shelters. Secondly, no one asked any question from survivors about temporary sheltering types. The temporary sheltering happened in different camps without considering survivor's life style and the role of gardens in their daily lives and economic dependency of families. There is a strong link between the economy of families in Bam and palm gardens. Access to palm gardens because of long distance from their temporary sheltering site was difficult and even impossible for old people.

This interview and comments about temporary shelters of survivors, and their situation with an architectural focus concerns firstly the lack of flexibility of shelters and secondly complexity of erection. With survivor's conditions that might have any minor or major medical treatment after rescuing, they have 2 options. To erect their shelters on their own after treatment or to wait for a long time to have someone to erect them. Finally, Dr Majid-Zadeh complains about the wrong construction methods of permanent sheltering and the weakness of management in post-earthquake scenarios.

4.4.8 Approaches of Experts related to the first 6 months temporary sheltering

This chapter for accurate identification of immediate architectural needs of survivors in the Bam post-earthquake scenario collated direct quotes of politicians who directly engaged with the Bam earthquake such as vice-president, the mayor of Bam, Bam City Council members, Kerman governor and UNESCO consultant in Bam.

Vice-president: "Bam is a famous garden city. Long term temporary sheltering can happen in their gardens. Statistics shows that 60% of survivors can stay in their gardens and the rest of them can be moved to camps" (Abadi, 2004:32).

In his opinion, this approach has many advantages such as ease of reconstruction because of easy access. Living in temporary shelters keeps them in the same life style and links them to their garden to manage their daily life. In addition, during living in their emergency shelter, they have access to some sustainable materials such as palm leaves and building materials left from the earthquake to upgrade their emergency shelter to mid-term.

Figure 4.12: The Iranian Red Crescent is erecting emergency shelter inside survivor's private lands (Ref: Fars New Agency Image Credit: Mohammad Fatemi)

Mayor of Bam: "If Bam City Council force survivors to live in prepared camps, the rest of the survivors who already chose to live in camps, would leave their camps too."[56]

Therefore, the preparation of temporary shelters by the local authority in survivor's private land costs more and needs more time in comparison to centralizing them in camps. Through research strategy in this thesis, survivors would be able to transfer their emergency shelters wherever they prefer and upgrade it with available secondary material options. Different lightweight primary and secondary material options are expanded in the Material Design Chapter Six.

A member of Bam City council: "Temporary sheltering in camps has social and economic damage for survivors in Bam that would be more than earthquake damages in the long term."[57]

He emphasizes that temporary sheltering in camps should be stopped and temporary shelters should be located inside of their gardens and next to their collapsed houses. However, because of weak management in the earthquake response cycle, emergency NGOs followed their usual strategy to plan a camp and erect emergency shelters inside a camp.

***Figure 4.13:** Iranian Red Crescent erecting emergency shelters inside the camps(Ref: Mojepishro.net Image Credit: Saeedi, Access date:25/06/2015)*

UNESCO Consultant Bam in post-earthquake scenario: "The Bam reconstruction plan should be a comprehensive plan to cover all of the survivors. It should reconstruct the economy of the city and as well as strengthen cultural infrastructures."[58]

Kerman governor: "When survivors requested to deliver their temporary shelters inside of their gardens rather than camps, we made new contracts with different

[56] Aftab Yazd Newspaper on Saturday 10/04/2004

[57] Aftab Yard Newspaper on Saturday 10/04/2004

[58] http://www.unicef.org/iran/BAM_EVALUATION_FINAL-_FINAL.pdf

contractors and it cost 25% extra for government. In total contracts were signed to prepare 29,300 units of tents and porta cabins. More than two thirds of these temporary shelters were arranged to be located in survivor's gardens."[59]

This quote and action to this quote from politicians shows that cost was not a primary issue in temporary sheltering after the Bam earthquake. Quality of life and survivor's satisfaction were more important for them. However, because of inefficient management in the earthquake response cycle, money was wasted changing the temporary sheltering strategy from camps to survivor's lands. In addition, training survivors how to erect their tents saved time and money for emergency NGOs. Therefore, this research facilitates emergency sheltering by designing a different range of self-construction emergency shelters that benefit from forms, materials and erection mechanisms from the public domain to maximise survivors engagement. Through this method, emergency NGOs do not need to train volunteers or in this case do not need to train survivors in post-earthquake conditions.

4.4.9 Six months after Bam earthquake

Approximately 50% of survivors from the Bam earthquake lived in tents then porta cabins inside of their private lands and the rest of the survivors were living in the same type of temporary shelters in different camps. During the first six months after the earthquake 50 billion Iranian Rials had been spent on temporary sheltering. Finally, the local authority responded to survivors requests despite the waste of temporary budgets. Approximately 60% of landscape recovery of the city had been done until July 2004. Out of the different survivors, farmers and palm garden owners were in better economic conditions and were hopeful to reconstruct their permanent shelters in a shorter time because these groups of survivors were able to sell their agricultural products in September. [60]

After six months, half of the city was ready for permanent sheltering. Many survivors collected many building materials from collapsed buildings to reuse. They had to keep those materials in a corner of their gardens. Some of the survivors already during temporary sheltering upgraded their shelter with local materials, which were mostly palm leaves. In the next step, emergency NGOs changed the temporary sheltering approach to move people from camps to the survivor's land. In the third step, as the figure 4.14 shows, survivors upgraded their emergency shelter with local materials such as palm leaves to cope with the direct sun rays in Bam which has a hot and dry climate.

[59] Shargh Newspaper on Thursday 05/02/2004 P.14

[60] Bam news- Azam khatam. Thursday 10/11/2004 p2-5

***Figure 4.14**: Survivors upgraded their tents with palm leaves (Ref:www.Mojepishro.net, Image Credit: Saeedi Access date: 25/06/2015)*

Below is the table of mistaken beliefs and facts in terms of social reaction and sheltering in the post-earthquake scenario; these beliefs and facts effect the research strategy for temporary sheltering.

According to the findings based on daily basis reports, social reactions were completely different. For instance, emergency NGOs and governmental organizations believed that survivors because of stress and psychological condition were not able to do any useful activity while people tried to solve their own problems. The Bam earthquake proved that in terms of emergency sheltering, when emergency NGOs with 20,000 volunteers were not able to prepare tents for survivors, this idea was proved that public engagement in emergency sheltering has potential. Therefore, NGOs started training survivors for erection of their tents and it was proved that they solve their own problems. This research, through these facts which are mentioned above and statistics collected from 20 survivors mentions that 90% of survivors engaged with erection of their tents in Bam, designed a self-construction emergency shelter for survivors. (See statistics emergency sheltering in tables 3.19 and transitional sheltering in 3.20).

In addition, local authorities because of knowledge of cultural situation and social structures in Bam played an important role to gather neighbourhood for emergency sheltering in survivors' private lands. They were efficient in reconstructing social structure of Bam during temporary sheltering. Research statistics show that for 10 % is not important at all, 25% important, 50% very important and 15% are dependent. (ref) Therefore, this research designed an extendable and flexible emergency shelters through modular design for survivors to maximize multi functionality in emergency shelters. For example, if a large family are going to live in a tent, they can attach 2 or 3 units to extend. In addition it can be used as field hospital, nurseries and other spaces that are normally larger than a tent. it is expanded upon this chapter.

In terms of sheltering, including temporary and permanent sheltering in Bam it is important to mention that; at the beginning NGOs and governmental organizations believed that sheltering in camp is better, security and crime would be less while as different experts and their reports explained crime statistics in camps were higher and in survivors private lands were less because of their neighbourhood that were looking after each other as family or friends.

Secondly, NGOs and governmental organizations believed that permanent sheltering should happen after temporary sheltering while survivors who were in their private lands, started reconstruction of their permanent shelters at the same time as temporary shelters. Thirdly, they believed that waste building material removal and excavation should be the primary action after an earthquake but they experienced that for immediate architectural responses, it needs to be done only for car and pedestrian routes as a primary action. Finally, they believed that construction of pre-fabricated temporary shelters is the solution while experience proved that survivors provide and upgrade their temporary shelters with readily available materials through local methods. The following table concerns the main assumptions and facts after six months.

	Assumptions in Bam	**Facts in Bam**
Social reaction after the earthquake	Survivors because of stress and psychological condition were not able to do any useful activity.	People try to solve their own problems.
	Local organizations would not be efficient after earthquakes.	Local authorities would try to be more efficient.
Temporary and permanent sheltering	Sheltering in camp is better. Security and crime would be less.	Statistics of crimes in camps are higher.
	Permanent sheltering should be after temporary sheltering.	Permanent sheltering can happen at the same time as temporary sheltering.
	Waste building material removal and excavation should be the primary action after an earthquake.	It needs to be done only for car and pedestrian routes as a primary action.
	Construction of pre-fabricated temporary shelters is solution way.	Providing shelter with local materials and local methods

Table 4.2: *Beliefs and facts in the Bam earthquake*

4.5 Problems of delivered emergency shelters to Bam: As expanded in the Literature Review, Shelter Box is an existing equipment and most efficient option for emergency NGOs for responding to immediate architectural needs which has many advantages and disadvantages. As experienced in the Bam post-earthquake scenario, these boxes had major problems in a post-earthquake scenario. Firstly, the Shelter Box organization had to send trained volunteers to post-earthquake scenarios with their boxes to prepare shelters for survivors and sending many trained volunteers was not possible for short time from abroad. Therefore, emergency NGOs had to train survivors in a post-earthquake scenario how to erect their shelters (Figure 4.5). Training how to erect shelters is necessary for existing emergency shelters. In addition, an urgent response is vitally important from trained volunteers to go as a team with boxes. Therefore, they should be on call all the time to respond quickly.

Secondly, existing emergency shelters are designed for short term sheltering for developing, developed and poor countries. These types of shelters usually get applied as mid and sometimes long term shelters in poor and developing countries which affect on efficiency and sustainability. According to the earthquake response cycle, survivors should pass the process of sheltering including emergency sheltering, transitional sheltering and permanent sheltering (Diagram 1.9). In this process, each step of the sheltering process gives time to provide the next step of the sheltering process and the quality of sheltering improves. For instance, emergency shelter provides time for emergency NGOs to organise the transitional sheltering stage that brings more advantages such as better quality of sheltering and more privacy for survivors. As statistics of field work in Bam show survivors in Bam were more satisfied during transitional sheltering. 70% of survivors were not satisfied by the quality of emergency sheltering (Table 3.29) while the percentage during transitional sheltering decreased to 35% (Table 3.20). The most important reason is feeling more privacy during temporary sheltering. This research through extendable emergency shelters and possibility of upgrading them from short term to mid-term is provides more privacy for survivors.

The possibility to extend emergency shelters through attaching each unit to other units does not exist in existing emergency shelters. For example, as expanded in the Literature Review before, existing equipment for emergency sheltering in post-earthquake scenarios are Shelter Boxes that consists of a tent for up to four people with other equipment such as a heater, light, first aid (de Magaz et al., 2005) while a family consisting of more than four people should live in separate units. The output of this research has a different range of prototypes with flexibility to attach single units to each other to create larger size emergency shelters. Therefore, this approach improves the quality of life in post-earthquake scenarios for survivors when they are in their worst physiological and emotional conditions.

Finally, the quality of life and basic human rights in every situation and condition is vitally important. For instance, in Haiti, all of the international emergency services responded to their immediate architectural needs and other immediate needs for relief such as medical aid. However, the local authority after leaving international NGOs a few months after earthquake, for different reasons including lack of budget and weakness of management were not able to provide transitional shelter for survivors. Therefore, survivors, who mostly were poor, had to live in emergency shelters for the long term. As the figures below show, different types of emergency shelter including tent with paper tube structures were delivered but 2 years after the Haiti earthquake survivors were still living in emergency shelters, which were not designed for mid-term or long-term settlement. As the figures 4.16 show survivors in the Haiti earthquake upgraded their tents with available materials which these type of tents were not designed for upgrading. Survivors' lives were affected negatively through living in emergency shelters for mid-term or long-term, because they did not complete the sheltering process of the earthquake response cycle.

Figure 4.15*: Emergency shelters after delivery in Haiti (McQuaid, 2003).*

Figure 4.16: *Survivors upgraded their emergency shelters 2 years after Haiti earthquake. (McQuaid, 2003).*

In addition, in the Bam earthquake, survivors and emergency NGOs received immediate national and international responses including emergency shelters as an immediate architectural need. After a few weeks the local authority could manage correctly and properly to provide transitional shelter for survivors. However, after delivering transitional shelters as mid-term shelters, the local authority, reduced the budget of permanent sheltering to start reconstructing Bam Citadel. As a result, the Bam ancient Citadel is out of UNESCO heritages at risk list.

> "The 37th session of UNESCO World Heritage Committee has removed Iran's ancient Bam Citadel from its List of World Heritage in Danger. "[61]

[61] Press TV, Iranian broadcasting TV channel, English Language on Tuesday 18/June/2013,6:26 PM http://www.presstv.com/detail/2013/06/18/309705/unesco-irans-bam-citadel-safe/

Therefore, some survivors, a few years after the earthquake, were still living in their transitional shelters. As figures 4.17 show, nearly five years after the Bam earthquake survivors were living in their transitional shelters next to their palm gardens in shelters upgraded with palm leaves to protect them from direct sun rays.

***Figure 4.17**: Condition of transitional shelters a decade after Bam earthquake (Ref: ISNA News Agency, photo credit :Rahim Baniasad Azad)*

***Figure 4.18:** Reconstruction of Bam citadel by local authority (Ref: www1.jamejamonline.ir ,Access Date: 04/02/2013)*

This research developed from these major problems in existing emergency shelters by designing creative self-erection emergency shelters for survivors to act independently in post-earthquake scenarios and therefore improve the quality and speed of response.

4.6 Sustainability of immediate architectural needs

The research in the next chapter expands on how to simplify erection mechanisms for designing self-construction emergency shelters. In addition, this research implemented sustainable, environmental-friendly and durable materials for longer-term settlement for emergency shelters. Discussion about this issue is expanded on in the Chapter Six Material Design. This chapter, after identification of immediate architectural needs that was achieved on a daily basis of consideration of an earthquake, focused on the sustainability of temporary shelters.

Generally, sustainable development happens through three items including environmental, economic and social activities. However, human social and economic activities have a direct effect on the environment. Therefore, this research considers different environmental factors to design a range of emergency shelters.

> "The main objectives of environmental sustainable design are to reduce, or completely avoid depletion of critical resources like energy, water and raw materials; prevent environmental degradation caused by facilities and infrastructure through their life cycle; and create built environment that are liveable, comfortable, safe and productive."[62]

[62] Sustainable, WBDG, sustainable committee, 09/04/13

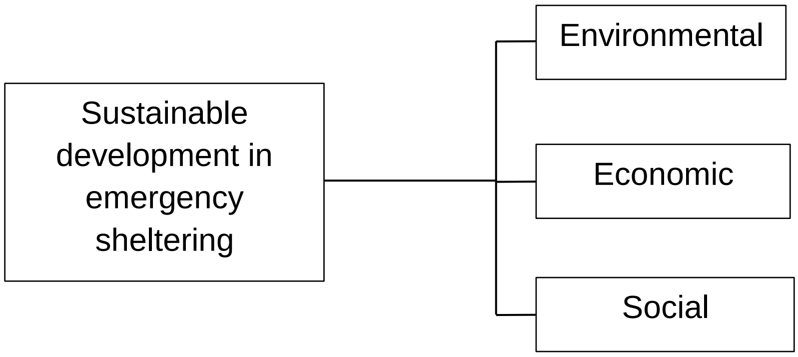


Diagram 4.1*: Sustainable developments in emergency sheltering.*

This research is concerned with different issues for sustainable development in emergency sheltering. This sustainable development is in different groups. This chapter as the Disaster Response Cycle and the next chapter on Structural Design Chapter discuss sustainable development through public engagement in emergency sheltering and how to engage survivors and emergency NGO to erect their own self-emergency shelters. The Structural Design Chapter and Material Design Chapters discuss sustainability through economic issues. This section of this Chapter and the Material Design Chapter expand on sustainable development through environmental issues in emergency sheltering.

Objectives for sustainable development for this research in emergency shelter are as follows:

1-To avoid wasting energy during settlement in emergency shelters through efficient methods for heating, cooling and lighting.

2-To provide self-construction emergency shelters with efficient types of structures.

3-To avoid material waste.

4-To implement environmental-friendly materials through proposed sustainable methods.

These objectives happens through different methods. As the diagram below shows all of the sustainable methods are categorized in low-tech and high-tech methods.

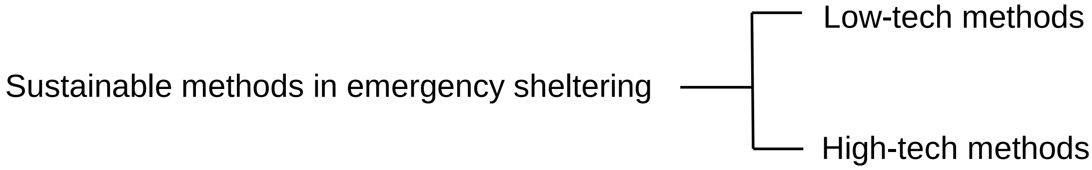


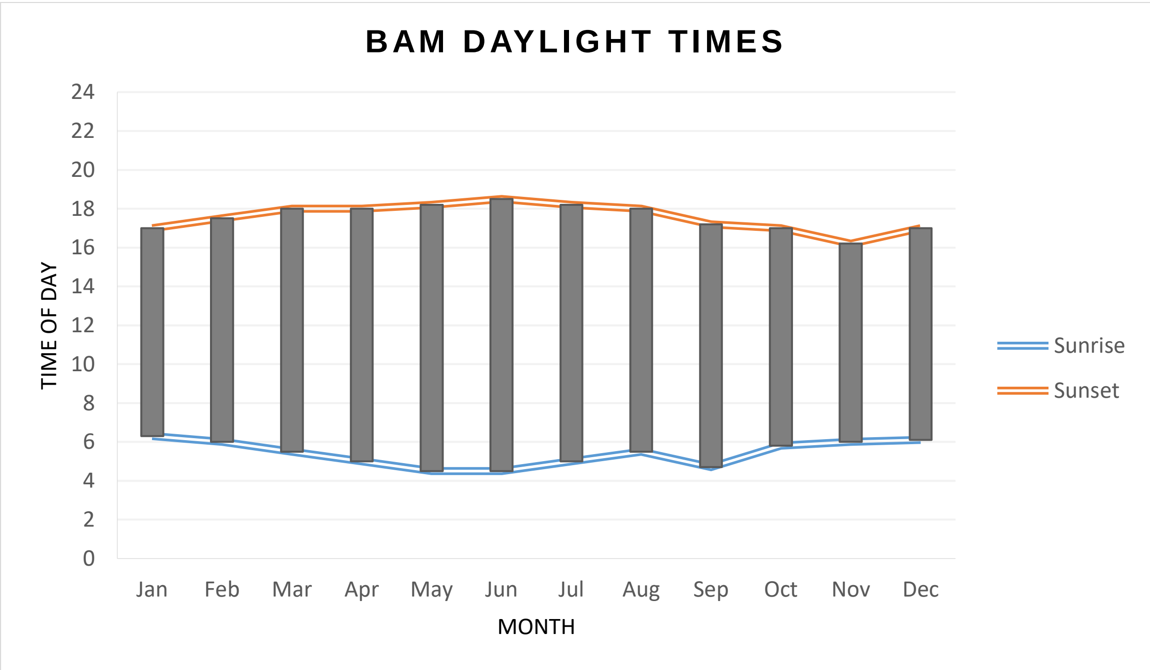
Diagram 4.2: *Categorizing sustainable methods for emergency sheltering*

4.7 Environmental concerns

This research designs an environmental friendly emergency shelter through material science, energy efficiency, orientation, sun and wind.(Ref) These items are output of other researches which have been discussed in the Literature Review such as Cold Climate Emergency Shelters. Application of these outputs let to design the most flexible and sustainable emergency shelters for Bam post-earthquake scenario because climatic conditions are different, availability of building materials for short term and long term sustainability are different and finally cultural issue for long term sheltering gets more important as local authority planned long term settlement in temporary shelters. The main approach for this research is to categorize sustainable low-cost and sustainable methods in low-tech and high-tech methods.

In existing tents as emergency shelters, survivors deal with different daily issues that effect the quality of the emergency shelter such as day-lighting, night lighting, ventilations, insulation. There are different low cost high-tech and low-tech methods for these issues. This research expands all of these items for existing emergency shelters and secondly prioritizes them to apply to this research.

4.7.1 Low-tech day lighting option: This research applied the low-tech method of natural lighting for emergency sheltering which was applied during Bam earthquake. The city of Bam on average benefits from approximately 12.5 hours of daylight every day, which can be the most efficient source of daylight during temporary sheltering. The graph below shows different sunrise and sunset times over a year.



Graph 4.1: *Sunrise and sunset times in Bam over a year (Ref: http://www.climate-charts.com)*

These kinds of low-tech traditional sustainable methods develops emergency sheltering through saving energy, an environmental-friendly approach to lighting systems and most importantly no cost in the post-earthquake scenario. Implementation of natural lighting makes emergency sheltering independent in terms of power and connection to electric generators. Below discusses how to apply natural lighting in emergency sheltering.

Figure 4.19: *Application of electric lighting system during emergency sheltering (right) and transitional (left) sheltering in Bam (Ref: right, www.tabnak.ir, Left: By author)*

The application of these types of daylighting methods that connect to infinite sources of energy, maximises sustainability in emergency sheltering in comparison with existing emergency shelters. Therefore, this research develops emergency sheltering with concepts of natural daylighting.

This research designed different number of small circular window on body of shelters in same shape of roof windows in Soltan Ahmad Bath, Kerman (Figure 4.21). These windows consist of two layers. Outer layer is transparent but inner layer is plywood to customise lights. The figure 5.18 in next chapter shows the erection mechanism of these windows. Survivors would be able to customise the required daylight inside the shelters through this concept. Some practical work has been done to prototype and evaluate this type of structure as window is expanded in the next chapter section Surface Deployable Structures (Section 5.8.1). These windows could be installed in the body of shelters which are in surface or strut deployable structures. This is illustrated in the portfolio section, strut deployable structures, page 16.

The figure 4.20 shows an idea of a daylighting system in emergency shelters that could be applied in different geographical locations and survivors or emergency NGOs are able to customise the required day light manually depending on their situation. Therefore, if they need more light they can increase the radius of the window and if daylight is too much, they can decrease the radius of the window manually to the appropriate size. The concept of the erectable window comes from the foldable roof in the Oita Stadium in Japan (section Surface Deployable structures).

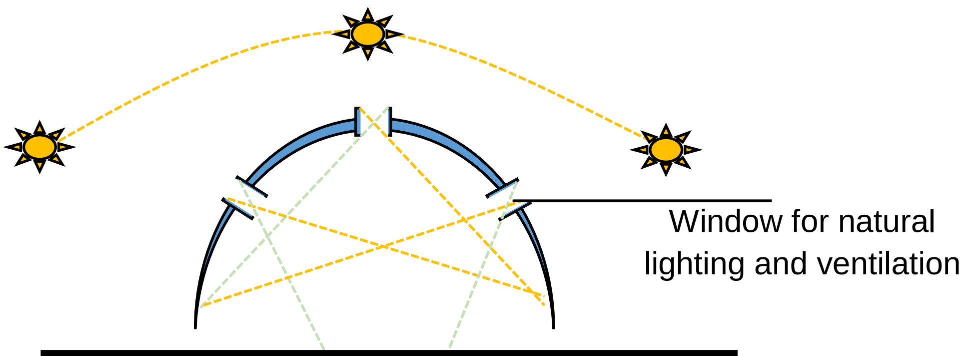


Figure 4.21: *Low-tech traditional natural lighting through roof windows in Soltan Ahmad Bath, Kerman, Iran (Left and middle) (Ref*: http*://deepartnature.blogspot.co.uk/), designed erectable window for emergency shelters (Right) (By author)*

4.7.2 Lighting options: As mentioned before, there are many examples in contemporary architecture, which benefit from low-tech or traditional lighting methods. This research considers the traditional night-lighting method as a familiar and accessible method in poor, developing and developed countries. One of these methods can be an electric powered night lighting system the same as Bam earthquake; a few hours after the earthquake a diesel generator supplied the required electricity in the Bam post-earthquake scenario. Battery powered light is another type of night lighting system.

An electric night lighting system might not be available at the beginning of the emergency sheltering or in different geographical locations. For this reason, this research predicts to apply

4.7.3 High-tech day/night-lighting option: Another lighting method in comparison with traditional methods is high-tech and it is not available in all the countries with different economic levels. The implementation of renewable energies needs technology. Out of green and sustainable sources of energy, most well-known are wind turbine and solar panels to supply electricity (Brown and DeKay, 2013). Generally, providing wind turbine in post-earthquake scenarios is not an efficient method in short term sheltering because in some geographical location with no wind it would be useless while solar energy system has more potential to be applied in this research. However, solar panels might have different levels of efficiency in different geographical locations but in Bam would be very efficient because of direct sun rays and hours of day lights.

Solar energy system has been implemented by the US army in Afghanistan where a gallon of fuel including transportation cost 400 US dollar.[63] This research is considering using solar energy for lighting and heating in emergency sheltering. These solar panels are available as panels and rolls. Therefore, both structural types of the prototypes have the possibility to implement this technology for more sustainability.

Figure 4.25: *US Army Solar powered tent and Solar powered camping tent (Ref:http://newsarchives.solarenergy-usa.com)*

Finally, this research applies these methods of lighting because firstly these methods are sustainable and environmental-friendly, secondly, power generators in post-earthquake scenarios are noisy which could be annoying for survivors and patients in field hospitals and causes vibration and more buildings damage.

In case of Bam, natural lighting would be very efficient and sustainable as Persian Architecture in Kerman has applied this method through history. In terms of application of solar panel, it should be mention that there is no solar panel manufacturer in Iran and there are not any building in Bam to apply this method of lighting. All of the solar panels in market in Iran are from other countries, which are high cost. However, this method of lighting cost more in comparison with other methods of lighting.

4.8 Research strategy to set in the scenario:

As expanded in the Literature Review, there is a unique disaster response cycle with a global strategy but methods of responding according to different locations and conditions might be different. Regarding the immediate architectural needs, there are differences in responding in post-earthquake scenarios in the different countries with different economic levels. In terms of planning in a post-earthquake scenario with existing strategies, there are two approaches. Responding to immediate architectural needs might be indoor or outdoor. In addition, there are different planning methods for camps that are mentioned in the section Camp Planning Patterns in the Literature

[63] U.S. Army Embraces Solar Energy, http://news-archives.solarenergy-usa.com/
Wednesday, November 28th, 2012 at 10:40 am by Solar Energy USA access date 13/03/2013

Review. Emergency NGOs can select different planning patterns because of the variety of un-controllable and un-predicable behaviour of survivors in post-earthquake scenarios. As the figures 4.26 show two different types of camps are shown here. The left figure is related to Amir Camp in the south of Bam and the right figure shows an indoor camp in Japan after an earthquake.

Figure 4.26: *Outdoor camp in Bam (Abadi, 2004) and indoor camp in Japan(Architect, 1996)*

These situations and methods of planning and sheltering are the same in all countries in the world. The only differences between developed countries, developing countries and poor countries would be the length of settlement in temporary shelters. The author observed immediate architectural responses by the Iranian Red Crescent during the Bam earthquake. In that earthquake, some of the survivors had preferred their emergency shelters as single unit tents close to their collapsed and destroyed houses. The author observed the reality of survivors who because of different reasons such as finding their family members who were trapped under collapsed buildings or collecting their personal belongings, were preferring to stay close to their collapsed buildings. Some of the survivors who found or survived completely with their family, relatives and friends were preferring to live outdoors in a sports field in Bam or indoors in a prayer room in an elementary school that did not collapse during earthquake. The building had serious damage such as cracks on main walls but still the building was stable and useable.

Therefore, this research with understanding and respect to different situations of survivors responds through creative single units. In addition, these units have the potential of attaching to each other to change from small single units to larger units for different purposes.

However, an emergency shelter for survivors is a multi-usage space for different cultures. Therefore, flexibility plays an important role. For example, the author experienced in Bam that when survivors want to sleep in their tent, they put rolled or folded mattresses and blankets on the floor to prepare their beds for sleeping. For eating, they rolled or tied their mattresses to store and stack them up in a corner of the shelter to have their food on the floor. The figure 4.27 is a good example of multi-usage emergency shelters for survivors. As it shows bedding items such as mattresses, duvets and blankets are in left corner of tent. The right corner of the tent as picture below shows; collected materials from collapsed buildings are stores. Finally kitchen materials for serving and warming food are stored at the font.

Figure 4.27: *Example of an emergency shelter, 6 days after the earthquake tents were multi-usage space for sleeping, eating, recovering. (By author).*

The author with knowledge of the variety of cultures, economic levels and different life conditions of survivors designed emergency shelters as multi usage spaces to be organized by survivors. Therefore, according to this research strategy, survivors can have their own life style in an emergency shelter. For instance, if survivors in other countries with different cultures want to have their food on the table rather than floor or to sleep on bed or male/female spaces, the output of this research provides the possibility of attaching other units to each other. For instance, survivors can sleep in separate units or keep partitions for more privacy (See volume 2, page 20). On the other side, if survivors with more family members need to live together for sleeping and eating in same unit it is possible to stay in the same shelter with a larger size. This research strategy of planning in emergency sheltering that provide flexible space for survivors, improves quality of life in post-earthquake scenarios directly.

Figure 4.28: *A family with 10 members had to live in three separate tents in their private lands after Bam earthquake. (Ref: Image Credit: Saeedi)*

This research, with keeping emergency shelters as multi-usage spaces is diagramming how survivors can extend their shelters. As the diagram for a single unit tent shows, the planning strategy would be the same as existing tents, which is multi-usage. Therefore, the planning strategy is exactly the same as the existing emergency shelters that are diagrammed in the Literature Review (see Diagram 5). The development of this strategy is; different parts of tent benefit from natural lighting and source of night lighting/ heating is designed for the centre of the shelter for more efficiency.

Diagram 4.3: *Diagramming of spaces in 2 extended units.*

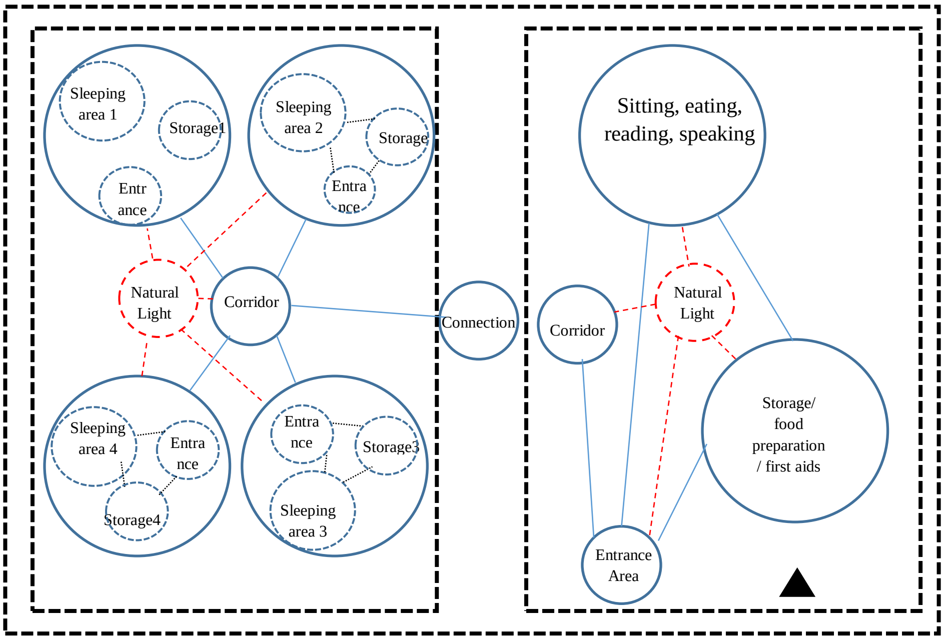


Diagram 4.4:

Relation of the spaces in 1 unit.

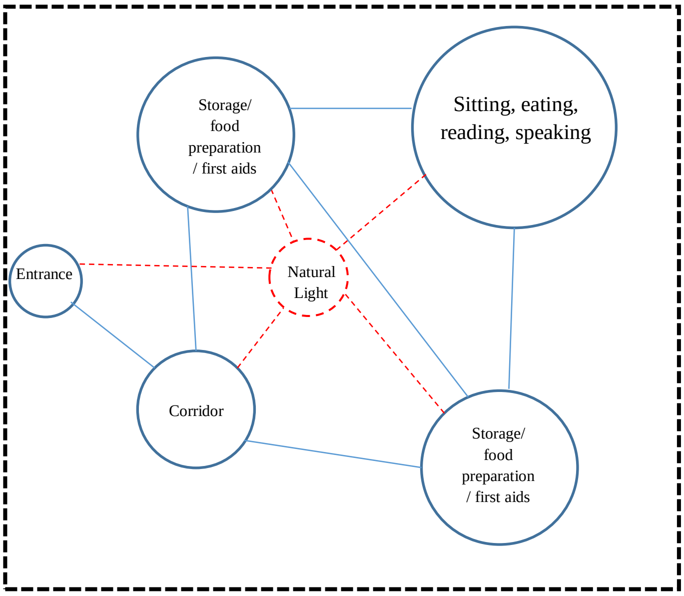


Figure 4.29: *Comparison of different single units of emergency shelters by the street in Bam (Right image ref: khabarfarsi.com, Left image by author)*

Figure 4.30*: Comparison of attached units of emergency shelters in Bam, (Right image ref: monti.blogfa.com , Left image by author)*

The other development through this strategy is for the first time, emergency shelters have the possibility to be extended to larger size units. This possibility helps emergency NGOs to erect their shelter in different sizes through simpler methods rather than huge scale tents, which usually need special equipment to erect. As the figure 4.31 shows emergency services rather than erecting long tents as field hospitals can attach different units of emergency shelters to have a large sized tent. As the diagram below shows, this diagram is an example of a multi-unit tent, which consists of a central unit. Each unit like a polygon can be connected to other units up from six different sides.

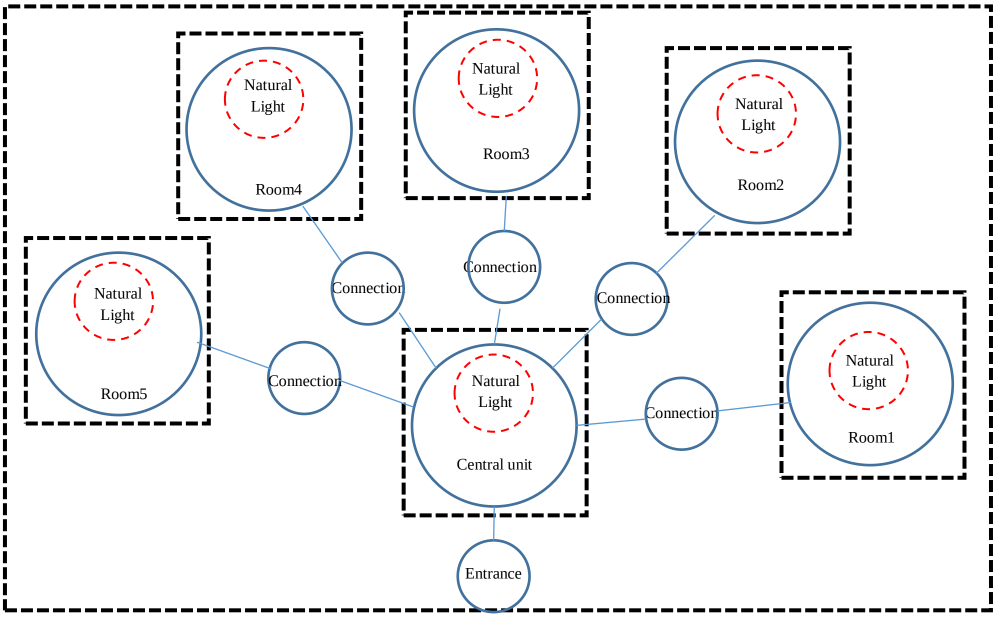


Diagram 4.5: *Diagramming a multi-unit tent (By author)*

Figure 4.31*: Comparison of multi-units of emergency shelter in Bam with multi-unit field-hospital in Bam (Ref: Left, by author, Right, Mehr News Agency, Image Credit: Younes Khani)*

As the figures 4.31(Right) show, an actual field-hospital in Bam consists of a different rooms in topography while computer modelling shows the same field hospital which consists of one entrance unit and 3 rooms for survivors. Each corridor is in accordion erection mechanism which is suitable for sites with topography. In addition, each room has the possibility to be extended to a double unit for larger size.

4.9 Chapter conclusion

This chapter primarily introduces people who are responsible of responding to a post-earthquake scenario as different NGOs. This people might respond nationally or internationally with a unique process. This chapter identified different stages of the disaster response cycle. Immediate architectural need begins with third step of relief. In addition this chapter identifies existing equipment for architectural responses as a single tent for up to four people that records show that in longer term would not be efficient in different aspect such as energy saving, sustainability, durability and multi functionality. Therefore, this research developed emergency sheltering by designing a multi-usage self-construction space that has potential to be erected by survivors. Self-construction emergency shelter would happen through the simplicity of the erection mechanism and familiarity of lightweight materials. This multi usage space that has potential to be extended can be used as field hospitals, field kitchen for emergencies.

This chapter expanded disaster response cycle, important lessons learnt from Bam earthquake and how those lessons affect on emergency sheltering. This research identified weaknesses of existing equipment of emergency sheltering in real situation that existing tents are not efficient in terms of energy saving, are not flexible space for different purposes. For instance, families with more than four family members, do not have possibility to extend their shelters in Shelter Box as a latest equipment for emergency sheltering. It has only one size for a family up to four members. Secondly existing emergency shelters are not sustainable and environment friendly in long-term uses. Materials of exiting emergency shelters such as tarpaulin are petrochemical material that in long term leads environmental toxicity. Finally, Shelter Box organization as biggest emergency shelter provider stated, existing emergency NGOs in best conditions need to provide three days training for volunteers to send with emergency shelters.

The differences between transitional shelters and emergency shelters in post-earthquake scenarios are listed below which this research designed long term emergency sheltering closer to transitional shelter for developing and poor countries.

- Transitional shelters are for longer term settlements
- There is more time in post-earthquake scenarios to provide transitional shelters in comparison with emergency shelters
- There is more time for the planning of infrastructure and sheltering for transitional shelters while emergency sheltering might occur in outdoor crisis points or indoor crisis points immediately.
- Cultural issues become more important in transitional sheltering in comparison with emergency sheltering with a global strategy.

This research with identification of immediate architectural needs and the gaps, which were mentioned in Literature Review, develops those gaps through designing different ranges of creative self-construction emergency shelters.

This chapter expands the earthquake response cycle and identified survivors' immediate architectural needs on a daily basis considering the Bam post-earthquake scenario. This chapter discussed the weaknesses of existing equipment of emergency sheltering and strengths of existing strategies for emergency sheltering in real situations.

In addition, it explained the responsibilities of emergency NGOs and different services which survivors received during the Bam earthquake. It critiqued the existing earthquake management and response to the immediate architectural needs during the Bam earthquake in different stages including delivering, erecting emergency shelters for survivors, waiting time for trained volunteers to erect delivered emergency shelters or conducting training classes in post-earthquake scenario when survivors were not in good physiological and physical conditions.

This section, summarises the outputs of this chapter. Generally, most of the identified immediate needs after an earthquake should happen as an activity inside a space or should be delivered as equipment from a shelter.

Action	Requirement
Evacuation of threatened people	Central command tent to manage
Emergency rescue of trapped people	Rescue equipment such as hydraulic scissors, trained dogs etc.
Administering first aid to the injured survivors	Field clinics
Transportation of the injured to hospital facilities	Field hospitals
Temporary sheltering	Sheltering engaged people including survivors for recovery
Providing food, water and other emergency items	Field kitchens, field stores, etc.
Immediate psychological support to survivors	Nursery, elderly houses, security units etc.

Table 4.3: *Relief actions and required spaces as immediate architectural needs*

As expanded on the disaster response cycle consists of different stages with the first step of the cycle relief, which includes all immediate actions and needs. All immediate actions and required space for those actions are listed above. Out of the different immediate actions and required space, some immediate needs should be responded during the first few hours. In fact, these items are supporting relief actions.

Action	Requirement
Purification of water	Water tank
Providing toilets	Emergency toilet tents/ transitional toilet units
Providing a covered bin station	To protect from sun and rain

Registering injured survivors through placards	Field clinics/ field hospitals
Registering dead bodies with photography	Security units tents
Securing post-earthquake against robbing	Security units tents

Table 4.4: *Supporting actions for relief during first few hours*

The next part of this chapter describes the Bam earthquake from the author's view and critiques different activities, advantages, disadvantages and potentials. For instance, families with more than four family members, did not have the possibility to extend their shelters while they were living in Shelter Box; the latest equipment for emergency sheltering which has only one size for a family up to four members. Secondly existing emergency shelters are not sustainable in long term uses. Materials of exiting emergency shelters such as tarpaulin which is a petrochemical material that in the long term leads to environmental toxicity. Environmental toxicity is expanded in Chapter Six, Material Design. Finally, emergency NGOs including the Shelter Box organization as the biggest emergency shelter manufacturer should train volunteers to send with emergency shelters while this research in the next chapter considers deployable structures, simplified and applied in emergency sheltering to design self-erection emergency shelters for survivors.

In the process of sheltering, emergency shelters and transitional shelters could be considered as an architectural response to humanitarian crises. These kinds of architectural responses are usually architectural solutions in manmade or non-manmade disasters and bring design services for survivors of these disasters. In this chapter, emergency shelter is known as short term sheltering, transitional sheltering as mid-term sheltering and finally permanent sheltering as long term sheltering. This research designed emergency sheltering as short term temporary sheltering closer to mid-term sheltering through upgrading and extension of units.

This research with identification of immediate of architectural needs develops it with more flexibility. In other words, this research in the next chapter with integration of low-tech structural options provides the possibility of extending emergency shelters as an immediate architectural need for different uses. For instance, survivors or responders have the chance to live with all of the family members, relatives and colleagues. in the same tent that improves quality of life in those condition. The next chapter considers structural design in emergency sheltering.

This chapter primarily introduces people who are responsible of responding to a post-earthquake scenario as different NGOs. This people might respond nationally or internationally with a unique process. This chapter identified different stages of disaster response cycle. Immediate architectural need begins with the third step of relief. In addition, this chapter identifies existing equipment for architectural responses as a single tent for up to four people that records show in longer term would not be efficient in different aspect such as energy saving and sustainability.

Therefore, this research developed emergency sheltering by designing a multi-usage self-construction space that has potential to be erected by survivors self-construction emergency shelter would happen through simplicity of erection mechanism and familiarity of lightweight materials. This multi usage space that has potential to be extended can be used as field hospitals, field kitchen for emergencies.

This chapter tried to expand disaster response cycle and important lessons learnt from previous earthquakes and how those lessons affect on emergency sheltering. Therefore, this research identifies weaknesses of existing equipment of emergency sheltering in real situation that existing tents are not efficient in terms of energy saving, are not flexible space for different uses. For instance, families with more than four family members, do not have possibility to extend their shelters as Shelter Box as a latest equipment for emergency sheltering has only one size for a family up to four members. Secondly, existing emergency shelters are not sustainable in long-term uses. Materials of exiting emergency shelters such as tarpaulin are petrochemical material that in long term leads environmental toxicity. Finally, Shelter Box organization as biggest emergency shelter provider stated, existing emergency NGOs in best conditions need to provide three days training for volunteers to send with emergency shelters.

Chapter 5:
Structural Design

For emergency sheltering

5.1 Introduction

In the case of emergency sheltering in the disaster response cycle, two factors are vitally important. Firstly, the deployability of the shelters to facilitate emergency sheltering in the disaster response cycle. Secondly, emergency sheltering through lightweight materials, which increase the efficiency of emergency shelters.

This research considers erectable and foldable structures in this chapter and lightweight materials in the next chapter to respond to the second research question, which is how we should develop sustainable temporary structures and infrastructures to support immediate or longer-term needs in post-earthquake scenarios?

The author, after experimenting with different types of deployable structures and prototyping in different workshops evaluated the potential of those structures through different lightweight materials because the structure and materials are linked together. In other words, different types of shelters seek specific materials and methods. For example, materials and methods in permanent sheltering are completely different from emergency sheltering. As a result, this chapter and the next chapter are going to discuss the primary research question.

- How should we develop sustainable temporary structures and infrastructures to support immediate or longer-term needs in post-earthquake scenarios?

Generally, erectable and foldable structures are known as deployable structures.

> "Deployable structure is a generic name for a broad category of prefabricated structures that can be transformed from a closed compact configuration to a predetermined, expanded form, in which they are stable and can carry loads. Due to this inherent transformability, deployable structures can be considered a special case within the broader class of adaptive structures." (Gantes, 2001:7).

Existing emergency shelters, such as tents which are foldable are a kind of deployable structure with foldable surfaces. This research focused on the historical type of erectable and foldable structures, which have the potential for emergency sheltering. In addition, this chapter investigates on deployable structures with an architectural focus to simplify the erection mechanism for survivors. This research categorize structures for prototyping and simplify the appropriate groups of deployable structures that have the potential to be implemented for emergency sheltering. Finally, the tabulated output of the consideration of deployable structures with an architectural focus demonstrates the possibilities of erectable and foldable emergency shelters for prototyping with appropriate material options.

The geometry, shape, form, function, erection mechanism and the proportion of structures in every shelter can be different. These factors of shelters might refer to an area where that material or form or geometry is more popular (Piesik, 2012). For example, palm leaves as a material option in permanent sheltering in Persian Gulf countries is a popular material option (See Section 1.8.5 and 1.7.1). These factors can shape cultural design, which in the process of the disaster response cycle becomes more important. This research focuses on architectural aspect of cultural design. Generally, different cultures and society has its own criteria and standard of excellence for cultural design. In Bam, people do not live in tribes as a social structure. They live in a big city with good economic condition in comparison with neighbour cities. However, dependency of family members is high. They look after each other and they live in big families. In addition, daily life in Bam depends on palm gardens therefore throughout history it has affected in different factors such as architecture.

As the diagram below shows, and was expanded in the Literature Review (ref), cultural design is linked to the length of life in different types of shelters. For instance, importance of cultural design in permanent sheltering is more important in comparison with transitional sheltering.

In the existing disaster response cycle, which is a global strategy, single units of tents would be delivered to survivors with no consideration for cultural design. In addition, existing tents have no flexibility for survivors to live according to different cultures or lifestyles. Western, eastern or Middle Eastern survivors should live in the same life style in a tent. However, this research applied cultural design, as much as possible, to designed emergency shelters through flexible shelter design and modular design. It is expanded in this chapter. The research methodology is to engage survivors through the different range of creative self-construction emergency shelters. This concept develops emergency sheltering for short term and mid-term settlement in post earthquake areas. Through this method, survivors are able to decide how to use and change their emergency shelters according to their lifestyle without any special skills.

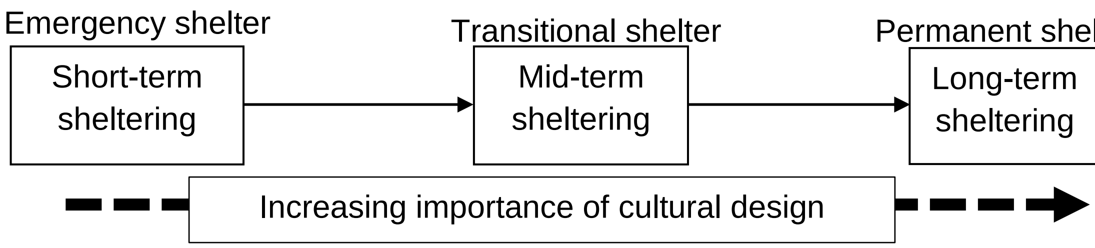


Diagram 5.1: *Importance of cultural issue in sheltering process (By author).*

The mechanism of the structure depends on the optimization of resources. The resources could be material, energy, money. These factors, in emergency sheltering, become more important because in short term settlements after earthquakes, it is usually more important to save time, money and energy.

Generally, sustainability and efficiency in the long term are more important in comparison with the short term. The efficiency in different aspects of emergency sheltering causes improvements in performance during emergency sheltering and the disaster response cycle. For example, the application of lightweight materials eases transportation and saves energy.

The aim of this research is to minimise the material use, energy waste and maximize efficiency through different methods/ techniques. Volume B of this research as portfolio presented different techniques of insulation for cold climates, details of upgrading shelters with palm leaves for hot climates and panel dimensions are presented to show waste percentage in each sheet during cutting and prototyping. Finally, selected familiar material options and forms, which exist in public domain, are applied for easy erection to minimise sheltering process through a self-construction emergency shelter. The output of modelling and prototyping in workshops has developed the structural knowledge for this research during the last few years.

5.2 Structural science:

Generally, architects and engineers categorize structures according to their shape, form or their mechanism. They usually analyse structures with what they see from action and reaction of structures with different methods and different approaches (Sokolowski and Tan, 2007). In science and engineering, there is a method that the reactions to different types of structures can be predicted in different conditions. This method would be through simulation in engineering software. This research implements computer simulation and digital modelling to maximise efficiency to save time, energy and cost through different computer software such as AutoCAD and ANSYS CFD to simulation models and conditions for different purposes.

Analysis of the actions and reactions of structures in structural science are categorized into two groups, basic structural actions and complex structural actions (Drew and Otto, 1976). However, the scale of emergency sheltering and structures is related to basic structural actions because this research applies simple and formal geometrical forms, such as cubes or domes on the same scale as a person. Furthermore, multi units of emergency shelters in this research which are in larger size, each single unit acts independently in terms of structural reaction and it does not shape complex structural action. For example, the structural action of a shelter in cubic form is in basic structural action. With the extension of an emergency shelter through attachment of other cubic forms, the final shelter still would stay in a cubic form but on a larger scale. Extension of emergency shelters is one of the developments of this research because emergency NGOs in Bam had to erect large sizes of tent with cranes (See portfolio Page 10) and it affected on process of sheltering, timing, work force and specialists.

Generally, the engineering focus of structural studies involves complex structural science and the architectural focus involves the basic structural reaction. Basic actions in emergency sheltering consist of compression, tension, truss, bending and shear in 1 to 3 dimensions. The table below from Drew and Otto individual research has been conducted on each item of the table. One and two dimensions are called earth based deployable structures and a 3D deployable structure is called “Deployable Structures based on pantographs” (Gantes, 2001).

	1-D	2-D	3-D
Compression	Column Strut Wall	Buttress Flying buttress Arch Barrel vault	Ribbed vault Fan vault Dome Thin shells Grid shells
Tension	Tie Cable Hanger	Catenary Suspension bridge	Shear free including: bubbles, Cable nets, shear resistant, fabrics, membranes
Truss	Non appropriate	Statically, determined such as: pin, jointed, warren truss	Space truss Lattice truss
Bending	Beams 1way slab Portal frames Vierendeel	Grillage 2way slabs (flat, ribbed, coffered)	Frames (truss)
Shear	Plate action Shear wall	Plate action Shear wall	Folded plates Torsion

Table 5.1: *Basic structural actions* (Drew and Otto, 1976).

Generally, basic structural actions are categorized by their action and as the table above shows, they are in five groups including compressive, tensile, trusses, bending structures and shear. For example, a compressive structure is type of structure that develops compressive stresses under axial loads. Tensile structures consist of elements that are under tension because of external loads. Trusses are horizontal or vertical elements that are in compression and are connected by hinges to other stable elements. Bending structures consists of an element that is under bending stress because of external loads and shear structures are a type of structure that are stable with continuous and various stresses. For example in the building industry snow, wind and rain cause forces and movement to the structure (Drew and Otto, 1976).

This categorization helps this research to select appropriate groups of structure for emergency sheltering with simple functions. In addition, it should be mentioned that different types of structures are categorized by their functions and mechanisms. This research implements a simple mechanism with low-tech methods to design self-construction emergency shelters for post-earthquake situations and the special conditions of survivors.

In complex structural actions, implementation of new technologies, such as composite materials or composite actions, improves the efficiency of complex structures but in some cases because of the implementation of technology the price of the final output increases. For instance, this research rather than using traditional methods for strut cutting used laser cutter plotter, which costs. Familiarity and simplicity of materials and forms in prototyping lead to effective self-erection emergency sheltering and public engagement, which is one of the important factors in the research methodology. Different workshops have been conducted to evaluate the potential of self-construction emergency shelters. Through these workshops, erection and modelling of emergency shelters were tested with different age groups (See Volume B pages 25, 31).

Mathematics and structural Design:

Structural design in the building industry is a mathematical and physical subject to design and simulate the structure of the buildings that load or resist. Structural science is based on mathematical calculations for loading or resistance. In addition, structural design depends on physical shapes, forms and materials used to have different reactions in terms of loading and resistance (Terzidis, 2006). Generally, structures are categorised by their mechanism or shapes and the shapes consist of geometrical patterns. All of these geometrical patterns are analysable by applied mathematics or computer software.

Algorithmic design is a method of computational design, which is based on applied mathematics. This kind of architecture combines architectural science and artificial intelligence together (Terzidis, 2006).

> "Through algorithms are becoming widespread in many design and fabrication industries, perhaps their best use is in architectural design, where they can enable designers to work in intuitive and non-deterministic ways" (Terzidis, 2006:32).

Algorithmic design leads to much creativity in designing forms and spaces. Furthermore, algorithmic design, artificial intelligence and engineering are all linked together. Computational design facilitates designing. In addition, algorithmic design, because of the many possibilities in math and specifically algorithms, can provide many alternatives in design.

This research, after identification of appropriate outputs for emergency sheltering, started digital modelling through different software. Secondly, modelled on a small scale for experimenting its erection mechanism and finally prototyped on the actual scale to test it through different age groups and evaluate its potential as self-construction emergency sheltering and the simplicity of erection.

As portfolio presents, Taxonomy page shows different identified erectable and foldable structural options, which have potential to be applied as self-construction emergency shelters (See portfolio Page 11). All of these options in taxonomy page have been prototyped and tested. Between surface deployable structures, type seven is selected as optimum design for sheltering and type three for linking 2 units of surface deployable structures. Architectural and technical information are provided in portfolio (Pages 12-24). In addition, deployable geodesic dome were selected as optimum design between strut deployable structures. The advantages, disadvantages and technical details of different options are presented in portfolio.

Each option were modelled digitally through AutoCAD and Sketch up to document elevations, sections and planning. Furthermore, each option were modelled in small scale with paper for surface deployable structures or plywood for strut deployable structures. (See volume B, page 11 taxonomy sheet). Finally with prototyping actual scale of each option efficiency of options were evaluated with different age groups (See volume B, Pages 29-31and 41)

As the figures 5.1 show, mathematicians can find algorithmic patterns in symmetrical geometric patterns too. The figure below shows the algorithmic design of foldable structures. As previously stated, symmetrical geometries have more potential to be erectable and foldable in comparison with other geometrical patterns.

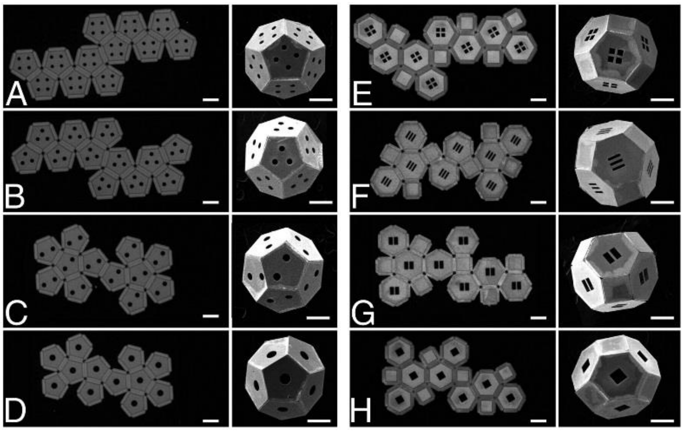


Figure 5.1: *Foldable algorithmic structural pattern.*
Ref:www.pnas.org Access date 05/07/2013

5.2.3 Structural design process:

According to the United Nations manifestos regarding natural disasters, which were previously stated, such as those from UNDRO (Gostelow, 1999) and UN Human Rights (Morsink, 1999), this research considers the typology of structures which have potential to be applied in emergency sheltering. Therefore, deployable structures, out of the different types of structures have been selected because of the many advantages including the potential in prefabricating, erectability, self-erection by survivors and potential to adapt the structure according to the geographical condition, climatic conditions while other types of structures cannot be flexible as much as deployable structures.

Generally, deployable structures in contemporary design are becoming more important. It can be applied from huge scale design such as BC place[64] with the biggest cable net deployable roof in the world (Schmaus, 2012) to small-scale erectable/foldable structures in equipment such as the shutter of photography cameras or robotic equipment for medical surgeries.

Structural design methods are different in developing, developed and poor countries in the building industry. However, the emergency shelters because of the low cost, small scale and quick sheltering, it is possible to manufacture them out of post-earthquake scenario then they can be transferred to post-earthquake scenario. In fact, this research focuses on erection mechanisms of pre-fabricated emergency shelters as self-construction emergency shelters. The process of manufacturing, assembling and productions are actions that occur before the earthquake. Emergency shelters should be manufactured and produced by emergency NGOs before earthquakes. (see section ref). This research has designed different range of self-construction emergency shelters that should be prototypes before earthquakes as a first step and after delivering, they have potential to be upgraded with local materials as second step. This research with the experience of the Bam earthquake has provided different information for upgrading prototypes for hot climate in Bam (See volume B, Page 23) and cold climate (See volume B pages 20-21).

This research, during the process of structural design for emergency sheltering with an architectural focus, considered different factors that affect development in emergency sheltering. These factors, which different parts of the previous chapter expanded on, are:

1. Flexibility to extend emergency shelter as much as is needed in post earthquake scenario (x ref).
2. Stability of structures for long term sheltering because the length of settlement in different areas with different economic/ climatic conditions are different. In the Bam post earthquake scenario, emergency NGO started providing transitional shelter after 7 months (x ref).
3. Low cost emergency shelter in comparison with existing tents for emergency sheltering because if it gets more expensive than existing tents, NGOs will prefer to use the existing tents.
4. Positive approach to environmental challenges such as climate change, global warming, carbon emission.

All of these factors shape the structural design items for this research. On the other hand, other factors with an engineering focus have affected the structure of emergency shelters differently. For example, this research applies sustainable material options, which are low cost and familiar to maximise sustainability and public engagement for self-construction emergency shelter. In addition, all of the material options for short

[64] BC place is a multi-usage stadium in Vancuver, Canada

term and long term emergency sheltering are expanded upon in the Material Design Chapter.

Different efficient high-tech and low-tech methods are implemented to minimise the number of possibilities. For example, practical experiences of research (see portfolio) proved that structural design is an important factor for the design of lightweight emergency shelters. It affects other items such as energy saving, ease of transport. Engineers have their own factors for structural design. They facilitate the implementation of technology such as analysing climate conditions, analysing landform conditions, soil conditions, quality of materials, and availability of materials (Addis, 1994).

With all of the factors and requirements from engineering and architecture, the design process for emergency sheltering in this research can shape a diagram. The original diagram comes from "The Art of Structural Engineering" (Addis, 1994). The original diagram was designed for permanent shelters with an engineering focus. Therefore, with the engineering experience of the author in the building industry, consultation with experts[65] and supervisory team, this research formed structural design diagram for emergency sheltering (Diagram 5.2). In fact, this is a developed diagram of William Addis but this diagram has an architectural focus for temporary sheltering. This research follows this diagram for prototyping.

[65] Engineers such as Hooman Atefi who is a PhD student in structural engineering, Queens Belfast University and Mr Hamid Tavassoly who is an experienced civil engineer with 20 years work experience in National Rail

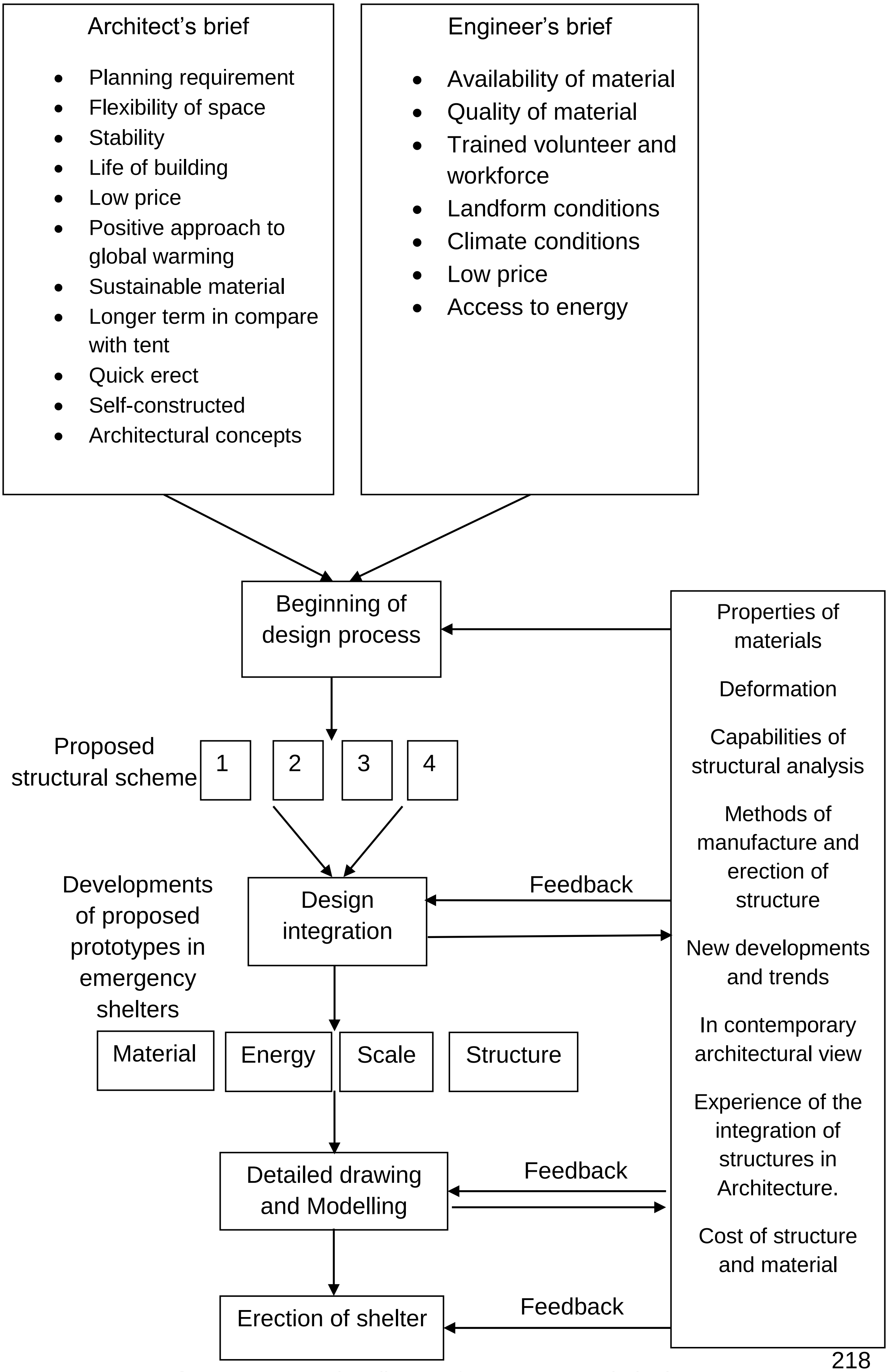


Diagram 5.2: *Design diagram for emergency sheltering*

Different items of this diagram from architect's brief and engineer's brief are expanded in Volume A of this research. These Items are expanded in Chapters Five and Six.

primary and secondary material options with different properties are proposed and tested through different factors (see Chapter Six) for short term and long term sheltering. Then different structural schemes in page 11 of the portfolio were proposed to apply with proposed materials to experiment. During digital modelling, small scale modelling and actual scale modelling different factor such as deformation, methods of manufacturing, erection mechanism, cost were considered. Finally, with analysis of prototypes structurally and experiencing selected materials options, optimum design from both groups of structures is selected. Different architectural drawings and technical details are presented in portfolio for each prototype. For instance, architectural drawings of optimum design for surface deployable structure are presented in page 12 of the portfolio and technical details for upgrading with secondary materials are presented in page 14 and 24, lighting 15-17.

5.2.4 History of deployable structures

Throughout history, erectable and foldable structures have been used as transitional shelters for nomadic tribes in many countries but these were permanent transitional shelters. Investigation into this kind of permanent shelter shows that these permanent transitional shelters are multi-functional for different daily activities that can be a concept for emergency sheltering in this research. These types of permanent transitional shelters need training to erect. Therefore, these type of shelters do not have the potential to be a self-erected in emergency situations in all areas. These types of shelters which are local are not quick enough to erect as emergency shelters in comparison with tents.

Figure 5.2: *Siah Chador in Zagros, Iran (left) and Teepees, North America (right) are the ancient transitional shelters (Ref: Tepeetent.co.uk)*

> "The fields of application of modern deployable structures are considerably different from, and more extensive than, in ancient times. Housing has acquired a more permanent character; therefore, it does not benefit from what are the main advantages of deployable structures. As a result, application of deployable structures on earth are found today mostly in relation to recreational proposes or temporary shelters for

victims of natural disasters, or for the construction industry" (Gantes, 2001: 12).

As mentioned, deployable structures, because of their ease of erection, flexibility in use and some features such as re-usability, are very important in temporary accommodation. This part considers deployable structures through history from ancient times such as Yurts to recent years such as the structures designed by NASA.

In ancient times, nomadic people tried to invent and apply these kinds of structures for easy relocating; a yurt is a case in point (Pearson, 2001). People in the past migrated from place to place, looking for a better quality of life so they invented some structures as shelter. These shelters were small, light, and portable, such as tents or yurts. Usually animals carried most of these shelters. They had to use these kinds of structures due to limitations in available materials, equipment, time, and construction possibilities. A yurt consists of struts, which are covered with fabric and rigid panels.

A yurt has advantages and disadvantages as a concept for this research. A yurt is a lightweight portable structure and it is sustainable and recyclable. However, these types of shelters take time and need trained people to erect. This research develops emergency sheltering through efficient material options, structural options, lighting and ventilation options to make emergency sheltering closer to mid-term sheltering. Secondly, this research designed prototypes with the possibility of upgrading to mid-term term sheltering for longer term usage with lightweight, cheaper material options, quicker to erect and more sustainable.

This research designed different range of self-construction emergency shelters through application of familiar forms and materials. Form of different structural options have been modeled (x Ref) but selected form is the one which is familiar in the Bam post-earthquake scenario according to local architecture (see portfolio). The concept of selected structural option which is in dome shape comes from local architecture in Kerman province. (x ref).

Existing nomadic traditional shelters need some serious changes in different parts to be efficient in a post-earthquake scenario as emergency shelters. First issue is erection time in nomadic permanent mobile shelter. For example A yurt is not able to be erected quickly enough in comparison with existing tents. However, it is more sustainable in comparison with existing tents. Yurts are design in different sizes while this research designed flexible and adaptable shelters to extend or attach to other units. Finally, as stated above, existing tents used by emergency NGOs cannot be self-erection shelters and trained volunteers are required in a post-earthquake scenario. It is the same for yurts, which need experienced people to erect it, while one of the developments of this research is delivering self-construction emergency shelters.

It takes more time to erect a yurt if the person has less experience or no experience while this research applies methods and techniques to design a self-erection emergency shelters by survivors. For instance, the author tested a yurt in the University of Manchester with five undergraduate students from different subjects who had no technical skills and they did not have experience of living in a tent. These students spent approximately 45 minutes together and they could not erect a yurt after 45 minutes. In the other side, the owner of yurt with assistant of one student erected that yurt in 13 minutes. Figure below is erected position of that yurt with door and lighting system.

One of the development of this research is to design an extendable emergency shelter as much as needed to bring flexibility in post-earthquake scenarios and facilitate the response cycle. However, a yurt can be good example of a mobile shelter for this research. Different lightweight material options from nomadic traditional mobile shelters such as Yurt can be the concept for this research to apply for prototyping. Methods and construction details are good examples for upgrading emergency shelters. Other advantages of a yurt are traditional heating and cooling methods. In terms of natural lighting, this research applies more efficient methods from Persian architecture, which are expanded in Literature Review (x ref).

Figure 5.3: *General view of a yurt, which was tested in the University of Manchester (By Author).*

These initial structures could often be erected on the ground and could be covered mostly with local or handmade materials. There were some cases in the past when these kinds of structures were used in the roof of the buildings. For example, ancient Roman architects applied these structures to cover buildings to protect spectators against wind, rain, or sun. Other examples of these erectable structures are convertible umbrellas designed by Frei Otto (Drew and Otto, 1976) in Al-Nabbi Mosque to protect those people from the sun whilst praying (Sinclair et al., 2006). These examples in some cases have been the concept of emergency shelters this is expanded in this chapter (see section Sliding Mechanism).

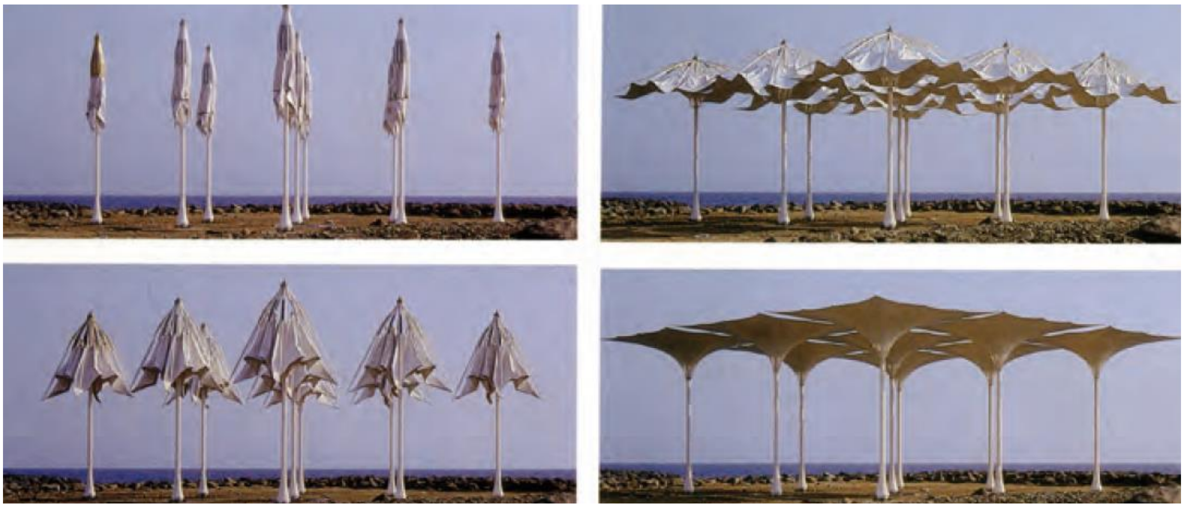


Figure 5.4: *Hydraulic convertible umbrellas, strut type, umbrella mechanism. (De Temmerman, 2007)*

5.3 Deployable Structure in Emergency Sheltering

There are few cases about emergency shelters with deployable structures, which have improved the disaster response cycle. Some cases such as “139 shelter” in sliding deployable structure or “Concrete canvas” in inflatable deployable structure are innovations that are expanded in this section from architects who tried to develop emergency shelters (Sinclair et al., 2006).

In addition, NASA, has done a lot of research into deployable structures, which could be useful for this research to apply and improve emergency sheltering. A deployable structure is the first priority in NASA in comparison with other types of structures, because of the advantages of prefabricating, ease of transporting, lightweight and finally, because deployable structures are easily erected during space exploration and its extreme conditions.

All of the mentioned advantages, which are stated above, are suitable for emergency sheltering in post-earthquake situations. However, the difference of deployable structures, which are being implemented in NASA with emergency sheltering is; the output of the emergency sheltering should be efficient economically while deployable structures in NASA come from high-tech materials and methods and budget are not an important factor in material and structural technology in NASA. In addition, all of the high-tech materials and methods in NASA come from scientific institutions such as Lincoln Lab, which is a federal funded laboratory for structural engineering[66] and specifically deployable structures while low-cost emergency shelters are the priority for emergency NGOs. NASA scientists in different institutions are still conducting research to improve the existing mechanism of deployable structures. The output of these institutions are considered in this research.

[66] https://www.ll.mit.edu/

Furthermore, it is noticeable that these days vast research about deployable structures is being expanded on different countries such as the United States, United Kingdom, Spain, Venezuela, Belgium, Iran, Israel. It means the initial research of Pinero from Spain around 40 years ago is global research at the moment (Section 1.7.9).

Basically, the form and function of a structure is directly related to three factors. Firstly, it depends on its efficiency, secondly, how it communicates with its users and its effects. Finally, aesthetically, how can it work and communicate with engineering and architectural issue (Diagram 5.3). This research responds to these factors to make a balance between these three factors. The intersection of these three factors are the most efficient location to make balance and response equally to all factors.

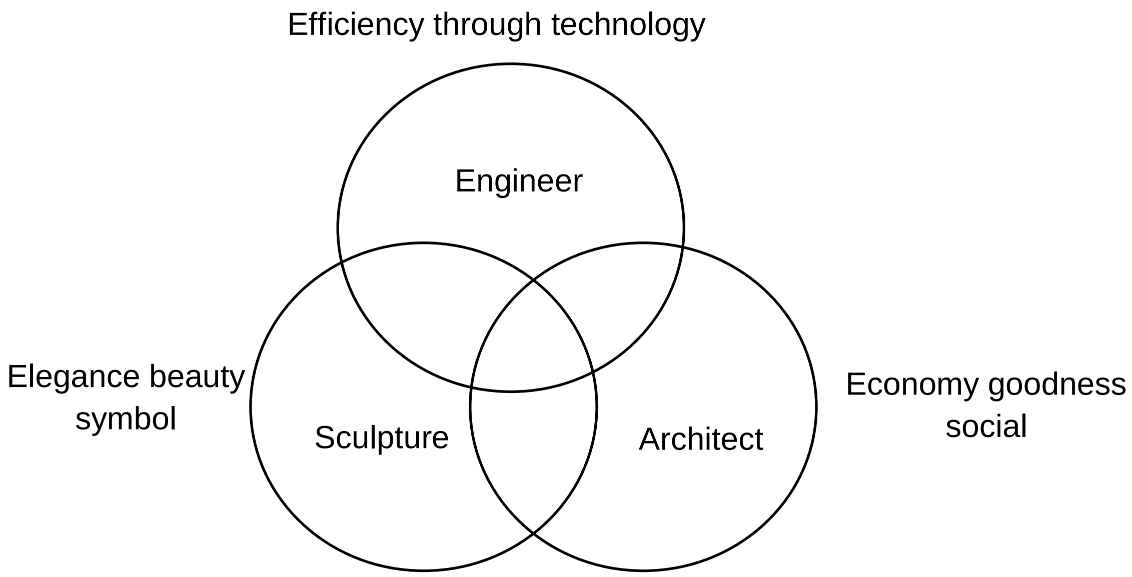


Diagram 5.3*: The art of the structural engineer (William, 1994)*

The output of this research is the result of application of deployable structures in the form of Kapar (X ref) which is local nomadic shelters. This research experimented and modeled 11 types of deployable structures to make emergency shelters closer to familiar local forms. application of architectural methods such as modular design increases efficiency of these shelters for different purposes. Application of lightweight local materials is another factor which this research aimed to balance three corners of this diagram. local lightweight materials affect on sustainability and cost of the project.

5.4 Public engagement to research

After approximately 100 years from the initial architectural response to humanitarian crises, this strategy became global in both developed and developing countries. Records prove that the use of emergency shelters in crisis points was experienced in the Japanese earthquake in 2011 as a developed country as well as in Haiti 2010 as a poor country. Therefore, all of the people in first few hours of post-earthquake scenario are in the same conditions.

Generally, existing emergency shelters are made from familiar materials, methods, forms and most of them have similar advantages and disadvantages. Architectural responses, including mobile architecture, have been improved during the humanitarian crisis time line, which starts from 1906 with the San Francisco earthquake and provided one of the great lessons in mobile architecture through providing prefabricated transitional shelters. (Sinclair et al., 2006)

About the disaster response cycle and specifically, planning of emergency shelters in post-earthquake scenarios, as previously stated in lessons learnt from previous experiences (x ref), architects, urban planners and engineers found that they should upgrade national building codes and infrastructures of cities. Furthermore, the local authorities should predict training plans for people before earthquakes and plan crisis points in their cities for emergency situations. These crisis points could be churches, schools and covered sports fields. During the Bam earthquake, emergency NGOs had to train some volunteers and even survivors to erect emergency shelters (see figure x ref). In addition, because of lack of efficient management and high level of damages local authority with private architectural studios started identifying empty lands as crisis points because schools and sport fields were damaged seriously. (arman shahr studio X ref)

Public engagement is one of important factors in this research that can facilitate the disaster response cycle. Emergency services, and in some cases architects, are trying to improve the quality of architectural responses through different methods such as materials, methods, structures in emergency sheltering. In addition, many architects and organizations have considered providing opportunities for architects in the world to think about better, quicker and cheaper emergency shelters. Records show that they have had a very good and positive response from all over the word from normal people with no technical skills and designers in every opportunity related to humanitarian crisis. It proves that it has so much potential to engage people to develop emergency sheltering. For example, in one competition on behalf of the United Nations was in the United States. Sinclair says:

> “Less than two months after calling for papers, we were sitting on our office surrounded by competition entry boards and models. More than 1400 designers from 50 countries responded to our call for entries. A total of 531 designs were submitted. Their schemes ranged from the pragmatic to the provocative. Designers proposed structures made from everything from rubble to inflatable hemp. The competition had crossed geographical boundaries and political ones, too” (Sinclair et al., 2006:147).

There was a very good reaction from architectural societies in the world to this humanitarian response, according to Cameron's experience for an international jury of architects and medical professionals, issues such as mobility, speed, storage, security, and community involvement were important factors. Between these items ease of transporting and speed of erection, were their priority. They believed that it is not easy for emergency services to cover the regions with difficulty in access especially when the weather is not good (Sinclair et al., 2006).

Records show that firstly, an international jury who were professional, were looking for mobility, speed, storage and security in architectural responses. These features are achievable with deployable architectural structures, which are expanded previously. Works from key designers such as Pinero, Felix Escring, Jean Perez and Zeigler's are expanded in the Literature Review (x Ref). Secondly, public engagement for architectural responses is very important to design and prepare shelters as emergency NGOs conduct training courses. Generally, public engagement is a potential although it was never applied in the correct way for emergency sheltering. It has been applied in training volunteers, which makes emergency sheltering dependent and slow because survivors should wait for emergency services and their trained volunteers to erect their tents. In addition, waiting for trained volunteers wastes time and it costs more for emergency NGOs.

However, the engagement of professionals and architects is more important. For example, some workshops conducted by Miami University[67] to collaborate with the people and professionals, community members, 65 international architects and designers to develop urban planning strategy for post disasters scenario and urban recovery. Finally, architects and environmental designers became united to support survivors for a better quality of life with people's experiences (Sinclair et al., 2006).

The author experienced in Bam, when the city and Bam citadel were shaken and destroyed, a group from the University of Miami that had been there to collaborate with them technically and financially but because of the political problem of Iran and USA ten years ago, the central Iranian government failed to accept their collaborations. Therefore, focusing on survivors to erect their own shelter develops the disaster response cycle in these situations, when trained responders do not have access to post-earthquake scenarios.

Throughout time with increasing number of natural disasters and cost of materials in the world, some architects such as Daniel and Mia Ferrara (Antonelli, 2005) with the collaboration of the Museum of Modern Art, designed a deployable shelter. Their shelter was designed by cardboard, which is quick to erect, light, easy to transport and is useful for emergency sheltering in post-earthquake scenarios or other short-term sheltering in emergency situations. However, the form and erection mechanism of their emergency shelter was similar to existing equipment and needed trained people to erect their emergency shelter.

[67] Miami University's Centre for Community Engagement in September 2004

In order to provide the best responses and improve the quality of life for survivors in the post-earthquake scenarios, the collaboration of individuals and NGOs is needed. This research enables the application of the latest technologies, such as deployable technology, including material science and structural design with an architectural view to provide mobile architecture for humanity. In terms of public engagement, this research simplifies erection mechanism through familiar local forms, material options to maximise public engagement (see Volume B portfolio). Finally, all of prototypes were tested by 3 age groups of people to evaluate potential of erection by people with no technical skills.

5.5 Application of lightweight deployable structures in post-earthquake scenarios

In this section, the research discusses the techniques and developments of emergency shelters in terms of structures and an examination of innovative application of deployable technology in emergency sheltering. This chapter focuses on existing technologies of structural engineering, the latest and most developed emergency shelters, potentials, advantages and disadvantages to provide different structural options for this research. These structural options, which have potential to be applied in emergency sheltering, are illustrated as taxonomy sheet in volume B, page 11.

After introduction of the key designers of deployable structures and identification of deployable structure research institutions, this chapter discusses the existing knowledge of deployable structure with precedents from around the world with an engineering focus. Secondly, lightweight deployable structures according to their potentials after experimenting are categorized. In the final step, deployable structures, their suitability in different situations or locations, and advantages and disadvantages are considered.

This research, for deep consideration on deployable structures, considers it with engineering and architectural focuses. Two distinct areas are

1. Light weight deployable structures with an engineering focus.
2. Light weight deployable structures with an architectural focus.

5.5.1 Deployable structures with engineering focus:

Emergency sheltering needs a light and quick structure to erect. In addition, it should be low cost and simple mechanism to erect for responders and survivors. Because of these requirements, deep consideration in deployable structures with an engineering focus is necessary. Cost is an important item in structural engineering.

> "Of the disadvantages associated with space grid construction, perhaps the main one is the cost, which can sometimes be high when compared with alternative structural systems" (Chilton, 1999:20).

As taxonomy sheet in portfolio shows, optimum design is selected for emergency sheltering in post-earthquake times (See volume B, Page 11). Out of these prototyped structures, 2 structures are selected which in terms of form are closer to ”Kapar” as local tribal shelter. one is designed in surface deployable structure which is low cost and sustainable and second one which is designed in strut deployable structures which is heavier and high cost in comparison with first one (x ref). the optimum design should be easy and fast to erect, fire resistant and sustainable to be an efficient emergency shelter choice. This output has been tested by different age groups, which is documented in portfolio page 41. (x ref)

Designed emergency shelter is prototyped in larger scale because of the potential of its structure. However, designed emergency shelters are extendable. Possibility of extension is an advantage in all types of structures which causes flexibility of spaces and more efficiency.

> “An advantage of use of the space grids is the efficiency of the erection for large span roof structures and especially on sites with limited access” (Chilton, 1999:18).

Deployable structures with an engineering focus based on their Morphology and Kinematics are expanded upon table below. Deployable structures with an engineering focus generally are categorized by their speed in erection and easy disassembly to reuse. Structural design and structural analysis in engineering involves mathematical analysis. However, this research applies the output of the appropriate deployable structural researches which are expanded in this chapter and assesses the potential of different types of deployable structures. The mechanisms of selected deployable structure types are experimented upon in prototypes for emergency sheltering. The priority in the mechanism of deployable structures is the simplicity of the erection mechanism to use as self-construction emergency shelters. Deployable structures with an engineering focus are categorized as shown in the table below.

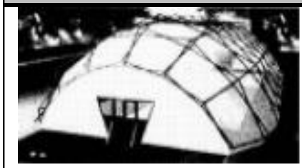
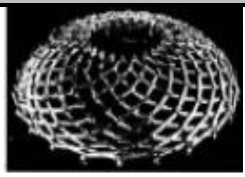
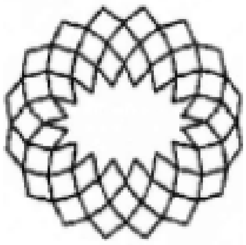
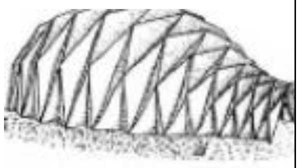
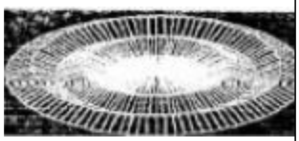
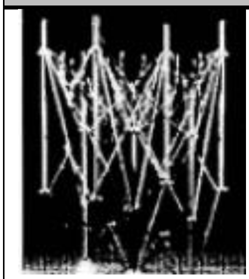
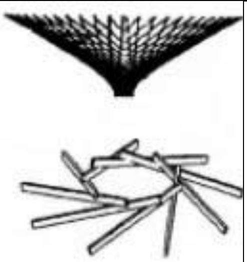
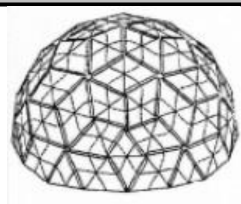
Morphology					
		lattice			continuous
Kinematics		DLG	SLG	Spine	Plates
		Scissor actions			Folded plated
		 Peripheral scissors  Radial scissor  others	 Angulated scissors 	Arches 	 Linear deployment  Radial deployment
		Bars			Curved surfaces
		 Articulated joints	 Reciprocal grids		
		Strut cables system		Tensional membrane	
		Tensegrity		Hybrid	Low/high level pressure inflatable

Table 5.2: *Classification of structural systems for deployable structures by morphological and kinematic characteristics (Hanaor, 2001).*

Deployable structures with an engineering focus are categorized by their shape and their erection mechanism. Generally, erection mechanisms of deployable structures are considered by mathematical calculations. All of the movements of struts or panels are fallowed by mathematical analysis. The table above is an output of the classification of the structural system for erectable and foldable structures according to their morphological and kinematic characteristics (Hanaor, 2001)

Those structures which are in the form of dome and cube from table above have been selected and prototyped in different conducted workshops (x ref) by students because of their potential to use as emergency shelter. For example, “Reciprocal grids” or “Radial deployment” because of their form were not selected or Low/high level pressure inflatable structure because of providing inflating equipment for short term and long term in all post-earthquake areas are not possible.

5.5.2 Deployable structures with architectural focus:

Deployable structures with architectural focuses can be divided in to many groups according to different needs and criteria. However, in the case of post-earthquake scenarios because of special situations, in terms of time and possibilities, categorization is limited to light and self-erection structures by survivors. Therefore, the categorization was done according to their mechanism. In the next step, the simplicity of deployable groups is considered to identify the best structural options for self-erection emergency shelters. This research considers emergency sheltering globally, the same as the existing world strategy for short-term settlement. Therefore, the mechanism of erection should be familiar and simple for people. This research implements the low-tech traditional erection methods with familiar forms such as erectable cubic or domes rather than complicated forms.

In structural design with an architectural focus, deployable structures are very well known in the field of implementation of lightweight materials (Winandy, 2006). In addition, these structures require less time to erect in comparison with other types of structures. In fact, these kinds of structures are space frames or tensile structures that are prefabricated and light, to occupy less space when they are erected closely together. They also make the most efficient use of the ground space available, which from an architectural view on emergency sheltering is a good factor for a post-earthquake scenario. With expanding structures, survivors are able to cover the maximum space that they need. The next step after designing is to focus on lightweight deployable architectural structures to develop and provide stable and efficient structures for emergency use and analysis through computer software. Technical details are provided in the portfolio pages 14, 21, 23, 39.

As expanded in the Literature Review (see section Pre-Fabricated Architecture) the research strategy is to manufactures, prefabricates and assembles panels of self-construction emergency shelters before earthquakes and store it for post-earthquake times. During earthquake response cycles, those shelters would be delivered to survivors and they would be able to erect their shelter on their own to save time and cost.

> “Erection time is a topic that also appears under the list of advantages. However, another common criticism of space grids is that the number and complexity of joints can lead to longer erection times on site.” (Chilton, 1999:20)

Because of complexity, health and safety, assembling and manufacturing process designed for emergency NGOs and erection for survivors. However, selected structural types for emergency sheltering in this research because of scale of the shelter and their familiarity are more simple in comparison with huge scale space grids.

In emergency sheltering, shelters should be prefabricated and ready to deliver and erect in the post-earthquake scenario. For example, in 1968, Linda Fuller and Millard Fuller designed self-construction mobile architecture with the concept of “mobile architecture and habitat”. Their design was a prefabricated mid-term shelter for survivors. Their design was first used in the Congo in 1973 with 100 cement unit houses. It took three weeks to provide mid-term shelters for all of the survivors, which was beyond their expectations (Arieff and Burkhart, 2003). Later with experience of many earthquakes, they changed the scale of their work and established a foundation with the name of “Habitat for Humanity” for mid-term sheltering in post-disaster scenarios.

In addition as previously in section 1.7.10 stated Buckminster Fuller’s concept, which is “more with less”, can be effectively used in this research for more efficiency in emergency sheltering. The efficiency can happen in different aspects of sheltering such as material use, lighting and natural ventilation in proposed shelters. These efficient concepts mostly have been used in permanent and transitional sheltering. Fuller’s innovation has the potential to be implemented in emergency sheltering in post-earthquake scenarios because it can save time erecting shelters, money and decrease the number of trained volunteers in these situations.

5.6 Developments

With the architectural consideration on deployable structures and an understanding of the situation of immediate architectural needs, this research out of different types of deployable structures, categorizes them into two groups with architectural focus to increase public engagement. The consideration in deployable structures with an architectural focus shows that all the deployable structures consist of surface or strut, which these two elements are easy recognizable. Therefore, deployable structures with architectural view are divided into

- Strut deployable structures
- Surface deployable structures

These erectable and foldable structures are made by panels or struts and could be in different geometrical shapes and erection mechanisms. In the next step, this research focused on the erection mechanism and folding in each group through prototypes such as the scissor erection mechanism. This method simplifies the understanding of mechanisms of erection and folding for the public.

5.7 Strut deployable structures:

The position of struts in deployable structures are in two situations. Firstly, two struts can rotate on each other. Secondly, two struts can be folded on each other.

A. Scissor-hinged mechanism

B. Umbrella mechanism

5.7.1 Scissor-hinged mechanism:

The main element in this kind of structure is the truss with a specific physical shape, which according to mathematical calculation can be based on a specific point to rotate on each other. In addition, it is connected to another strut. In fact, flexibility of the truts comes from each linear object, which is connected, to the next linear object by a joint. Therefore, rotation of each object is possible and controllable.

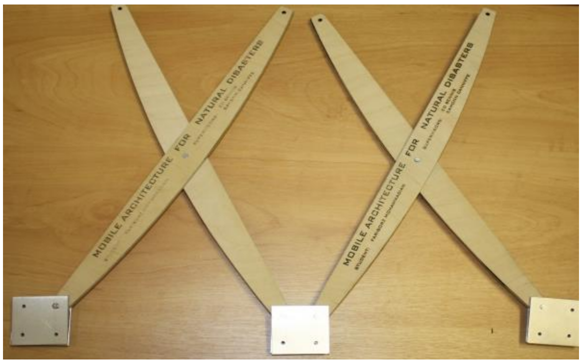


Figure 5.5: *Experimenting deployable structure in scissor action in workshop (By author).*

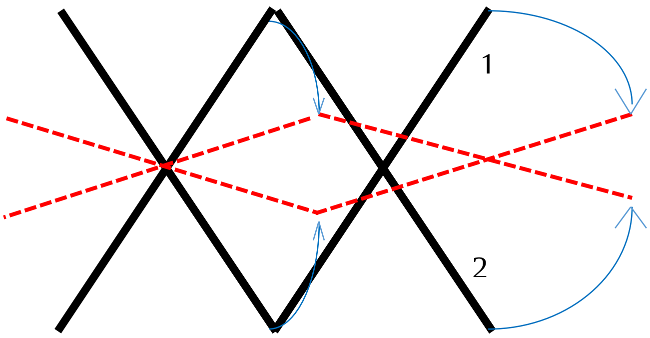


Figure5.6: *Rotation and erection of deployable structure with scissor action mechanism (By author).*

As the figures above show the mechanism of erection in the scissor action strut deployable structure are very simple and familiar for the public. In fact, their mechanisms are very familiar on a global scale. This research implements two iconic deployable structures utilizing scissor action in emergency sheltering. Firstly, Buckminster Fuller's geodesic domes. Secondly the "Iris Dome" in the MOMA exhibition which both are expanded on below.

Buckminster Fuller's Geodesic Dome:

This research implemented iconic deployable geodesic domes for emergency sheltering because of the advantages mentioned in section 1.7.9 (ref). However because of availability of materials in the Bam and prototyping experience this research could not be an efficient output for this research. In fact, structurally was an efficient option for emergency NGO shelter but in terms of material, output should be prototyped with steel or aluminium. This is expanded in Material Design Chapter. As the figures 5.7 show, this research prototyped different types of geodesic domes invented by Buckminster Fuller. However, the experience of prototyping proved that geodesic domes are not efficient for emergency sheltering for survivors. It can be applied in emergency sheltering for NGOs. This research is applies a developed version of the Buckminster geodesic dome invented by Emilio Perez Pinero and Felix Escig (Pinero, 1976) as a deployable geodesic dome.

There are different types of deployable geodesic domes; two types, with the potential to apply in emergency sheltering are expanded below employed in circular plan or rectangular plan. Research by Carlos Henrique Hernandez Merchan (Hernández Merchan, 1987) in MIT School of Engineering, with mathematical calculation demonstrates that deployable geodesic domes in an erected position can cover 12 times more space in comparison with folded position. For example, if the diameter of a deployable geodesic dome in folded position is 1 metre and occupies 0.785 square metres, in erected position it can cover 113.04 square metre. The figure 5.7 from his research can demonstrate its potential of erection through plan and elevation in both folded and erected position.

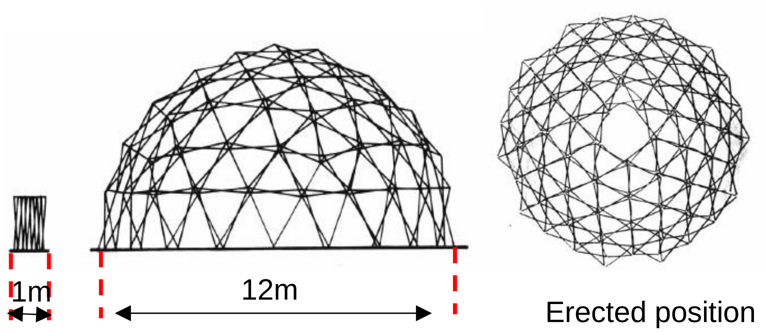
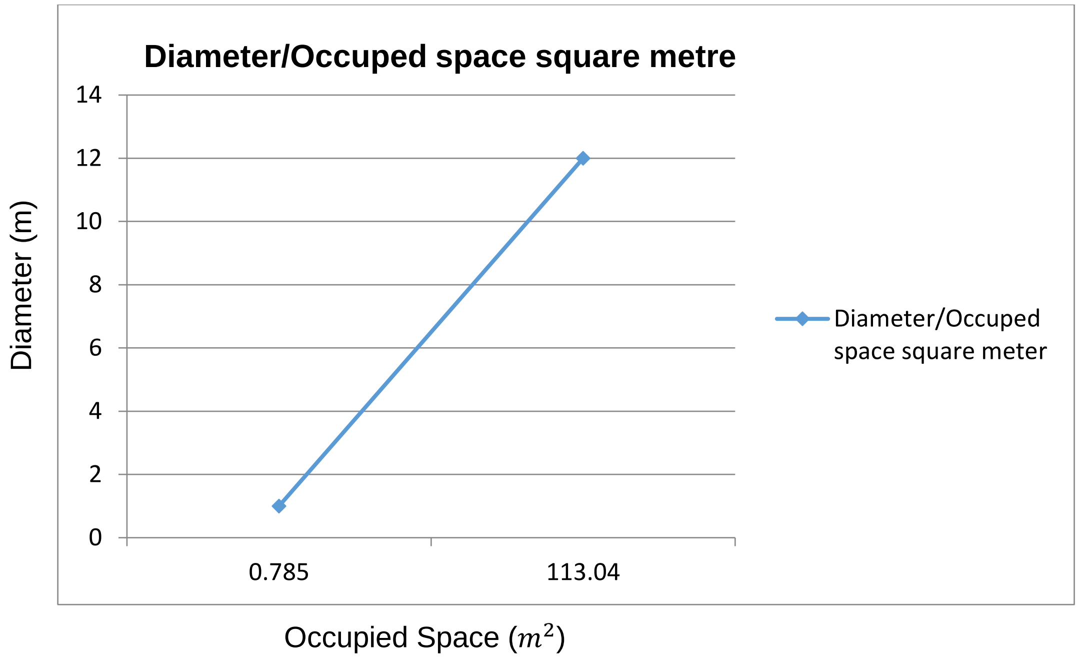


Figure 5.7: *Side view, top view and perspective of Deployable Geodesic dome utilizing scissor action (Hernandez Merchan,1987)*



Graph 5.7: Erection of structure with diameters/Occupied space square metre (By author)

This example, as the picture below shows, has been implemented in a different project as Seville swimming pool. It has been constructed with an erectable lightweight structure. This swimming pool in winter can be covered by erected deployable structure in rectangular plan and in summer can be opened by folding.

Figure 5.8: *Deployable cover for a swimming pool in Seville designed by Escrig and Sanchez. Image Credit Performance SL (De Temmerman, 2007).*

This research is apples the output of these structural innovations as a structural option for emergency sheltering with prototyping on a smaller scale as an emergency shelter because in the folded position it is very easy to store and in the erected position it can cover maximum space. In addition, in the portfolio, the process of construction are presented upon pages (ref) 13-15 and appropriate material options for prototyping scale 1:1 are provided upon page 24.

Iris Retractable roof:

As the second iconic deployable structural type utilizing scissor action, this research uses the output of the Charles Hoberman's research as the Iris dome (Whitehead, 2000). The Iris dome because of its similarity to a Kapar in terms of form, which is a familiar form in the Bam, was concerned as a self-construction structural option for emergency sheltering in post-earthquake scenarios. As Figure below shows the mechanism of erection, Hoberman's dome, is very simple and it covers maximum space.

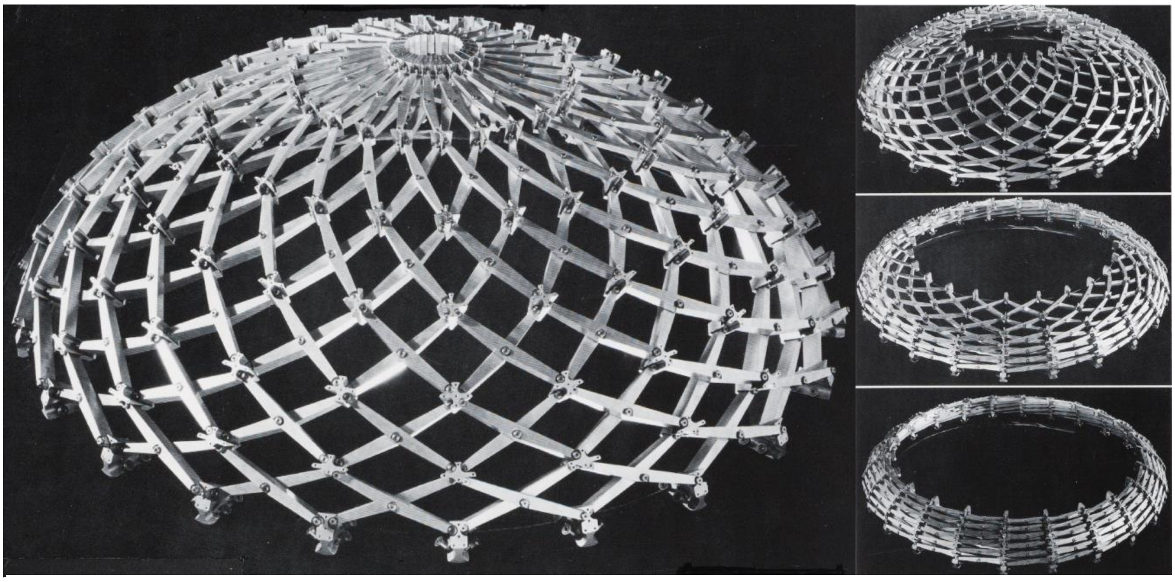


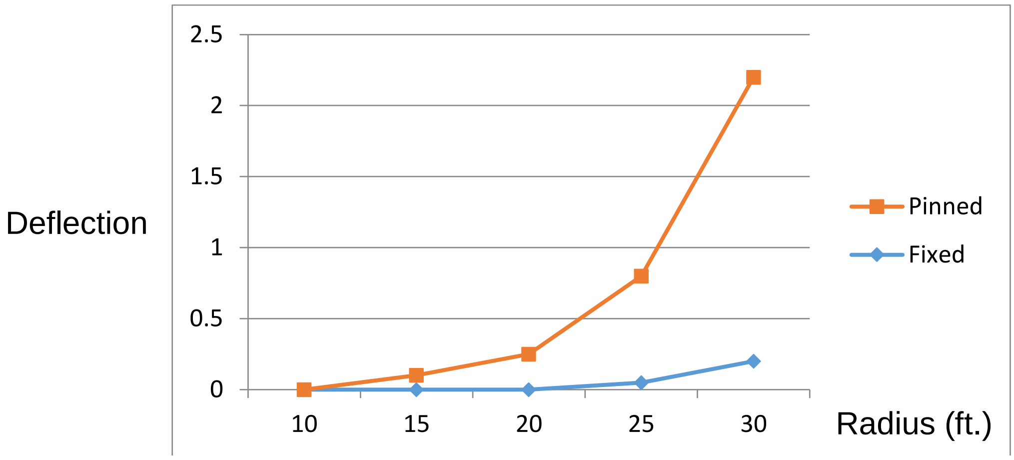
Figure 5.9: *Mechanism of folding and erection of Iris Dome by Charles Hoberman, Articulated date: 26 April 2013*
(Ref:http://www.architecturalreview.com.Accessdate:26/11/14

It has potential in erecting, folding and transforming, therefore structurally it has the potential to be implemented as a structural option in emergency sheltering. In addition, with an architectural focus, this dome is very flexible to transform into a cone or a dome. This research used this deployable structure type utilizing scissor action in the form of a cone for prototyping because in this form it would be small size and transferring would be more efficient as it is possible to stack up cones. This research applied this structural type to design a foldable emergency shelter but in terms of material and cannot be prototyped by plywood or cardboards. It has be to prototyped by steel or aluminium. Materiality of these structural option are expanded in next chapter.

Research from MIT University analyses the Iris dome mathematically. The output of this research is a table which can shows with the erection of the structure, how much space can be covered.

Radius (ft.)	Covered Area (sq/ft)	Roof load	Total load	No of division	No of hinges	Load per hinge
10	314.2	60	18.85	12	48	0.393
15	706.9	60	42.41	12	48	0.884
20	1256.6	60	75.40	12	48	1.571
25	1963.5	60	117.81	12	48	2.454
30	2827.4	60	169.65	12	48	3.534

***Table 5.3**: Analysis of shelter expansion (1st column) and space covering (2nd column) (Wolfe, 2013)*



***Graph 5.2**: Space span vs deflection of dome (Wolfe, 2013).*

As figures below show in the workshop the author, prototyped the iris dome with the same technical information based on wheels to provide the possibility of changing the radius of the structure.

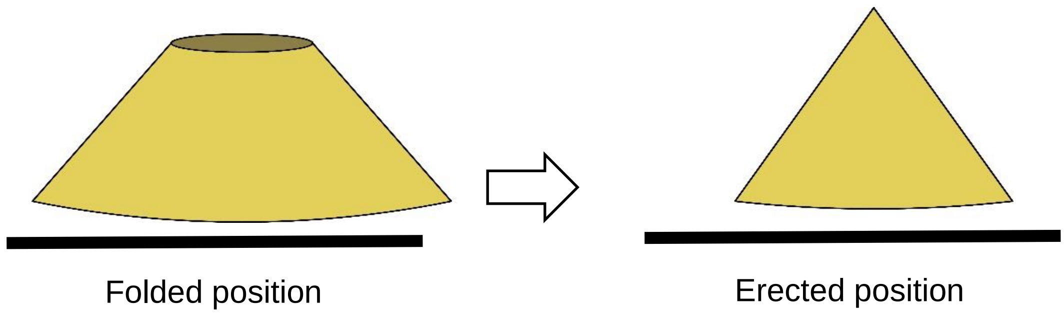


***Figure 5.10:** Folded and erected position of shelter (By author)*

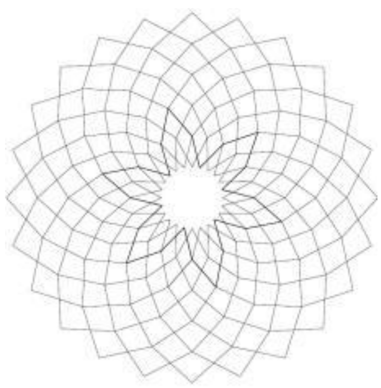


***Figure 5.11:** Top view of proposed structure option utilizing scissor action*

***Figure 5.12:** Deployable structure utilising scissor action with the concept of Hoberman's dome*

Therefore, this research prototyped an emergency shelter with all this engineering potential in deployable structures. In addition, these outputs can were tested the efficiency of the proposed emergency shelters in the portfolio. Finally, this research prototyped these outputs as a shelter in actual scale to assess its efficiency in reality.

5.7.2 Sliding mechanism (Umbrella mechanism):

The second group of deployable structures utilising scissor action is the umbrella mechanism. One of the simplest deployable structures, which everyone can use every day, is an umbrella. This kind of structure in a folded position is very small while in an erected position it can cover a big space.

This name is selected because of the familiarity of the function and form of the umbrella to the public. In this structure type, with the connection of linear elements to a main tube in the centre, it can be rotated and folded in vertical directions. This erection mechanism is exactly the same as an umbrella. Many developments have happened in the umbrella mechanism in different academic institutions such as Bauhaus. (Mann, 2004). These developed umbrella mechanisms are able to cover maximum space with less energy.

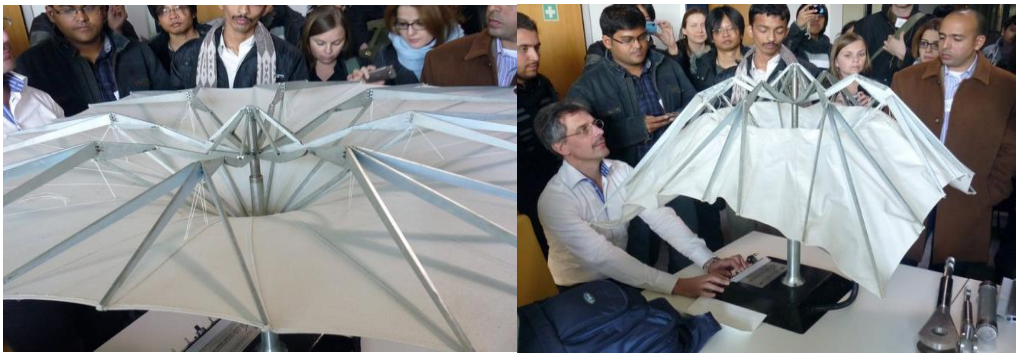


Figure 5.13*: Presenting an electric umbrella in an exhibition, Bauhaus 15/06/2009.*

One of the iconic examples of emergency shelters in strut deployable structure, which is working with the umbrella mechanism, is the “139 Shelter” which was designed by David Nixon in 1989 (Sinclair et al., 2006); his concept comes from an umbrella. This emergency shelter with the application of a deployable structure can cover up to 200 people. 139 Shelter has advantages and disadvantages which can affect this research. An advantage can be “139 shelters” are very easy to move and transfer as a huge scale shelter for NGOs. As the figure 5.14 shows, it could be transferred by air, truck or helicopter. Disadvantages could be its heavy weight and because of the huge scale of this emergency shelter a crane or truck is needed to erect this shelter. In addition, the 139 shelter cannot be erected as much as needed e.g. there is no option to have it as half erected shelter. It can be completely erected or completely folded.

Whereas with the prototypes of this research, which are in surface deployable structures, survivors are able to erect their shelter as much as they need.

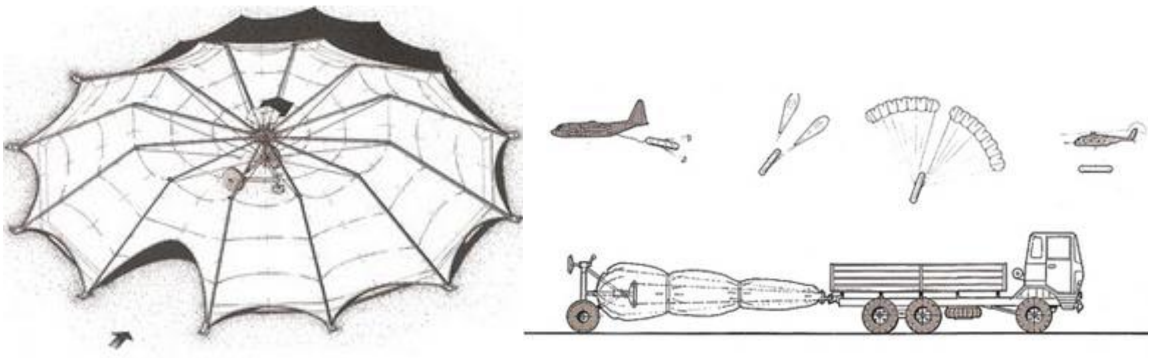


***Figure 5.14**: “139 Shelters”, possibilities for transporting the 139shelter (Sinclair et al., 2006)*

This research, between the mentioned deployable structures tested the scissor action deployable structure type for emergency sheltering because it has the potential to be customized in terms of size. It was an efficient structural type but because of experimental test it was not selected as an optimum choice because of limitation in material selection. This research could not prototype this structural type with cardboard and plywood. Experiments and prototyping in actual scale proved that in has to be prototyped with metal which makes it heavy weight structure and high cost structure.

Despite of their advantages it cannot be optimum choice. For example, survivors can erect it as much as they need while an umbrella mechanism has two positions. It can be in a folded position or an erected position. It cannot be half erected while deployable geodesic domes or other types of deployable structures such as accordion mechanisms can be erected as much as needed by survivors in post-earthquake scenarios while in an umbrella mechanism, it should be completely erected or it should be completely folded.

Furthermore, a deployable geodesic structural option in folded and erected position has the potential to have inner and outer layers installed for double-glazing. All of the construction detailing is expanded in portfolio. It improves insulation in emergency sheltering as well as natural ventilation while the umbrella structure type does not have the potential for any secondary materials as inner or outer layers to be installed.

5.8 Surface Deployable Structures:

In the second group of deployable structures, objects are in the form of panels and surfaces, which are exactly similar to strut structures where each object could be in tension, compression. In some cases, surfaces are continuous and completely in tension such as inflatable structures or gas tanks. In some cases surfaces consist of different smaller surfaces, which are connected with flexible joints to each other. Therefore, with all of the forms and mechanisms surface deployable structures are categorized into three groups.

Including A- folded structures or accordion mechanism, B-inflatable or pneumatic structures and C-telescopic

5.8.1 Folded structures:

This group of deployable structures is known as foldable structures, which like an accordion, can be folded and erected. An accordion mechanism deployable structure can be constructed as:

- One piece plate but with a flexible surface to fold
- More than one piece with solid surfaces and flexible connections

The advantage of a folded surface deployable structure is the possibility of construction with low-tech traditional methods such as origami. Therefore, survivors can erect and fold deployable structures with no technical skills. This approach helps this research for effective self-erection emergency sheltering. There are many examples of sheltering over the world with the accordion mechanism deployable structure such as Yokohama International Port as permanent shelter.

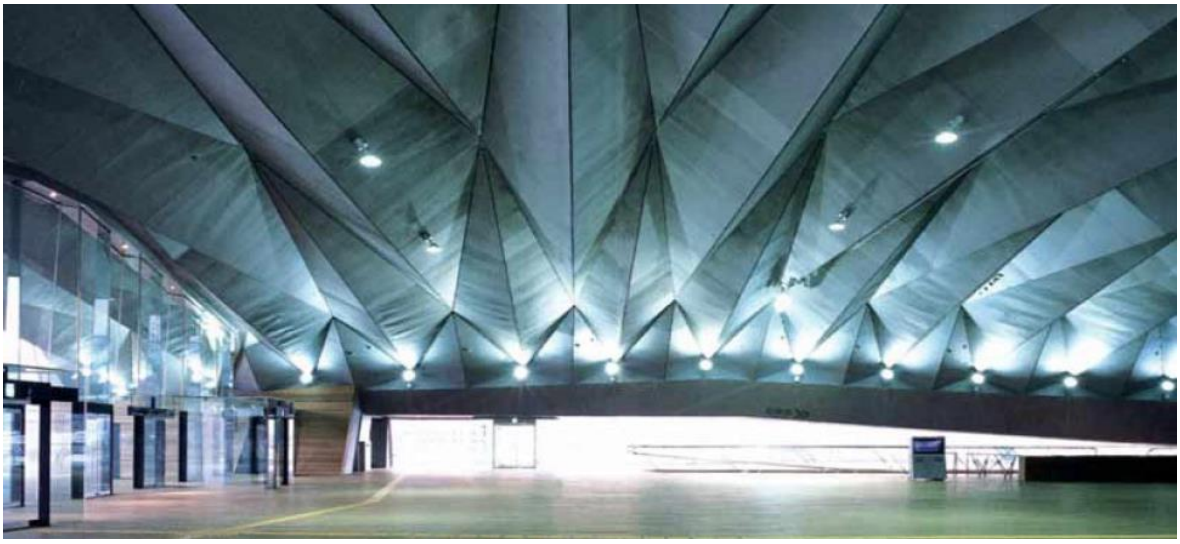


Figure 5.15: *Folded structure in permanent sheltering, Yokohama International Port (Ref: www.arcspace.com, Access date: 24/06/2013).*

One example of an emergency shelter in deployable folded architecture is “Global Village Shelter” by Daniel Ferrera in 1995 (Antonelli, 2005). His strategy to design this kind of shelter was simple instruction, a low cost shelter and easy to transport. The advantages of his work that can affect this research were; the weight of cardboard and foldable elements of the shelter provided a very light and small emergency shelter, which was easy to transport for emergency services. In addition, the price of the shelter because of simple material use was low cost. However, the Global Village is an existing emergency shelter, which was not self-erection completely, and needs two volunteers to erect the shelter. This research considers designing a different range of emergency shelters with the potential of extension while the Global Village does not have the possibility of extension. The Global Village is designed for a family of four members or less only.

Global Village shelter is an efficient option for emergency sheltering. However, there are advantages and disadvantages to apply Global Village shelter as emergency shelter in the Bam post-earthquake scenario. The most important advantage is; the Global Village shelter was made from laminated corrugated cardboard which is lightweight material option. Secondly it can be transferred everywhere when it is in folded position because it occupy less space in comparison with erected position. Furthermore, it is a low cost shelter because it is made by low cost material.

In the other side, there are disadvantages which this research avoids through different methods. Disadvantages of Global Village for the Bam Post earthquake scenario is; maximum four people in a global shelter is not enough because families in Bam generally are more than 4 people. There for 2 or 3 units are required. Therefore, this research designed attachable and extendable unit through technical methods (x Ref), secondly Global Village can be erected in average 30 minutes by minimum 2 people. Tools like screws and screw drivers are necessary to erect it while in the post-earthquake scenario providing different types of screws and screw drivers for all tents in a camp are not easy. Therefore, this research applies technical methods such as plastic rivet which need just click parts together to avoid disadvantages. Finally, Global shelter is in cubic form which is a familiar form while this research between different types of deployable structural types applies dome shapes because local architecture and tribal traditional shelter in Bam consists of dome.

Optimum design of surface deployable structure in this research is in accordion erection mechanism which do not need any instrument for erection in the post-earthquake scenario. However, this research for connection of prototype number 7 and prototype number 3 uses 8 plastic rivets through a channel. These connections do not need technical information. Technical details of this connection is provided upon volume B, page 21. (x ref)

Daniel Ferrera believes that the simple set up is more valuable than the aesthetics of emergency shelters and the structural mechanism of the emergency shelters plays an important role in the ease of setting up (Sinclair et al, 2006). With good and efficient structural types, it would be possible to make an emergency shelter as short-term shelter closer to mid-term shelter because an efficient structure would provide the possibility of upgrading with secondary material for long-term sustainability. Therefore, structure plays an important role in sustainability.

Generally, the surface structures because of prefabrication need less connection in preparation in comparison with strut deployable such as geodesic dome. It affect the cost of the shelter. In addition, the application of unexpected and low cost materials such as paper and cardboards are more efficient in terms of manufacturing and transport.

Figure 5.16: *Global Village Shelter (Sinclair et al., 2006).*

Figure 5.17*: Testing a self-erection prototype with people who had no technical skills (By author).*

Some practical works have been done to demonstrate the simplicity of different types of deployable structures. For example, the roof of the Oita stadium by Kisho Kurakawa & Associate has one of the most complicated deployable structures with an engineering focus. This types of roof in three dimensions does not have the potential to be implemented in emergency sheltering because the differences between the folded and erected position of the structure are not so different. As expanded in the previous chapter, this research implements two dimensions of this structure as windows for emergency shelters. It provides the possibility to customize the required natural light inside the shelter (See volume B, page 15).

Figure 5.18: *Prototyping two-dimension deployable structure constructed in Oita stadium (By author)*

Figure5.19: *Three dimension deployable structure constructed as roof in Oita stadium (De Temmerman, 2007)*

This research proposes a different range of deployable structure options for emergency sheltering because of the possibility of transforming from a closed compact configuration to a predetermined, expanded form. One of these deployable structure options is a mixture of umbrella mechanism and folded surface deployable structures. Jörg Student who is a researcher from Royal College of Art designed a foldable umbrella.

> "The body of design work is folded out of a single sheet of 3.5m by 14m corrugated polyethylene. Jörg Student was inspired by the structure of hornbeam leaves, the Ha-Ori shelter is foldable, light (weighting 36kg in total) and very sturdy, capable of withstanding icy winds and snow" (Trebbi, 2012)

Figure5.20: Ha-ori deployable umbrella by Jörg Student (Trebbi, 2012).

This research implements the same erection methods which is a folded mechanism to simplify erection of emergency shelters. However, a computer simulation in a structural analysis research, with the title of “A foldable umbrella structure-Developments and Experience”, demonstrates that the horizontal panel at the top of the umbrella during windy conditions has the possibility of deformation. Figure below shows, panels in dark blue are in minimum deformation because of the weight of the shelter and panels with pink colour are in maximum deformation risk under 1.2 kN wind.

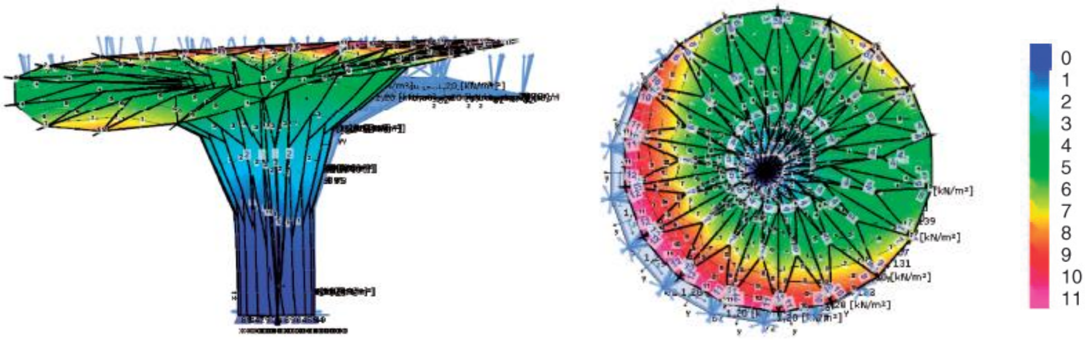


***Figure 5.21**: Structural analysis- deformation due to wind (Jaksch and Sedlak, 2011).*

This chapter proposes an erectable dome as a structural option for emergency sheltering, which in terms of erection, in comparison with the Ha-ori, the direction of erection would be reversed. Different experiments have been carried out to evaluate its stability. Firstly, a computer simulation has carried out to evaluate the stability and energy simulating. Secondly, it has been prototyped in scale one to one to test the erection mechanism and stability. As experiments and prototyping in actual scale proved, it has the potential to be implemented in emergency sheltering as a surface deployable structural option. In addition, this type of surface deployable structural option has the potential to be upgraded with a secondary material option for energy efficiency. It is expanded in portfolio page (x ref).

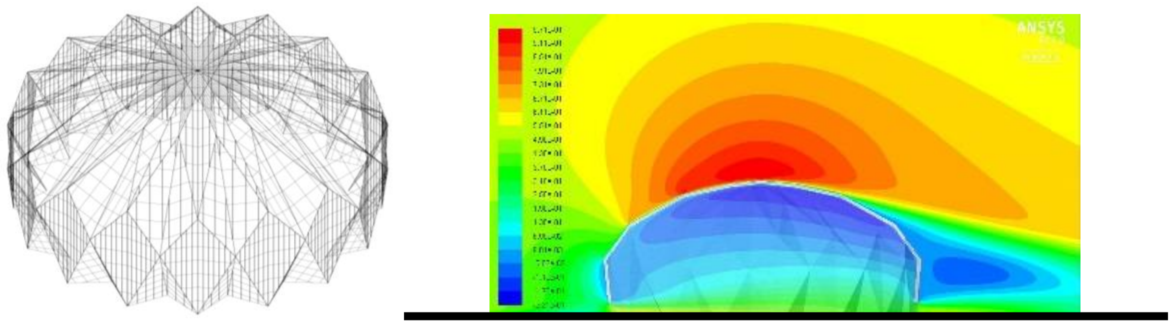


Figure 5.22: *Proposed folded surface deployable structures which are resistant against wind (By author)*

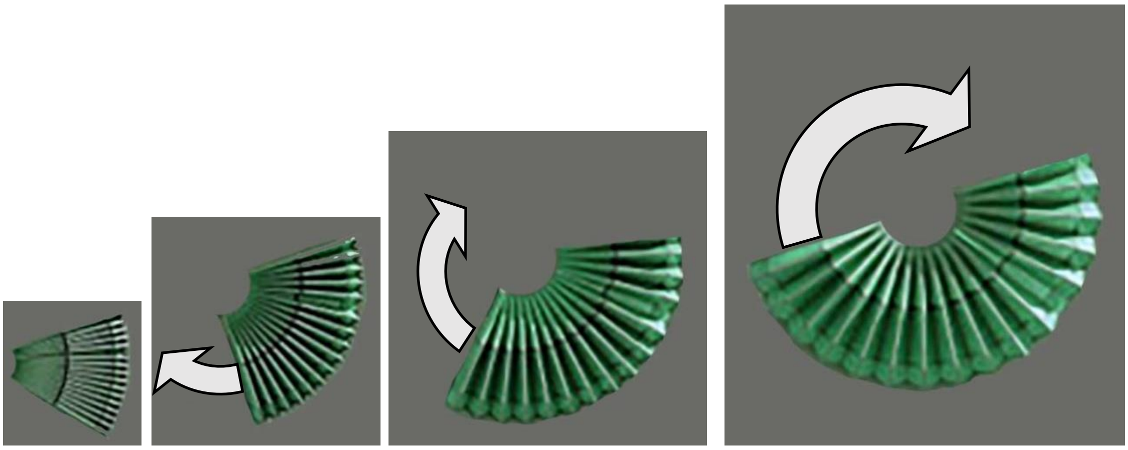


Figure 5.23: *Erection mechanism is in accordion mechanism (By author)*

For more information for digital modelling, erection mechanism and technical details of the prototype see the portfolio, pages 12-24.

Workshop experience:

During modelling and analysing in the workshop, it was experienced that the scale of the prototype is linked to the material and structure of the shelters. Alternatively, different scales of prototypes seek specific technical details. For example, during the workshop experience, it was proved that the bigger scale models should be made by other materials with different properties, which are stronger materials. It causes prototypes to be stronger and efficient in terms of strength and stability. However, all of these factors get less important in smaller scales of sheltering. For instance, prototypes in the figure below in a small scale were made from paper while for scale 1:2, 3mm cardboard was the main material option. For scale 1:1 thicker and stronger 10mm corrugated cardboard was used.

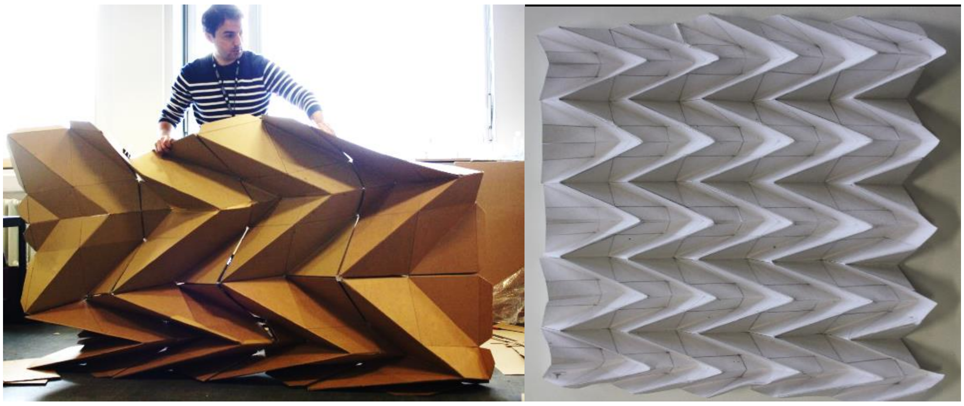


Figure 5.24*: Application of different material for different prototyping scale (By author).*

All the information about material science of constructing are expanded in the Material Design Chapters Six.

> Galileo in 1638 says: “a longer rope is usually weaker than a shorter one because there is a higher probability of it containing one of these weaknesses, not simply because it is longer” (Scheuermann and Boxer, 1996).

5.8.2 Inflatable structures:

This group of structures consists of a light and flexible layer (membrane), which with the application of different gas pressure between two layers of structure can be erected. In addition, there are possibilities to apply liquids, foams, or fillable materials to fill between two layers and erect. Therefore, the layers of a structure change to a stable and load-bearing membrane. The best example of this kind of structure is a balloon. The balloon is a flexible and non-stable form, which can be shaped and stabilised with gas pressure (Faridani, 2006).

This kind of deployable structure, has been very useful in short-term sheltering and used in many projects as emergency shelters. In addition, the second advantage of this structure type is its potential in natural lighting in comparison with other types of structures. There are many architectural projects in inflatable structure over the world such as green houses, shelters, portable exhibitions, roofs. Therefore, the most important advantage of this structure type would be the potential of natural lighting.

SPACEBUSTER can be mentioned as a transitional shelter in inflatable structures. As the figures below show Gallery front for Art and Architecture designed a quick inflatable shelter to “transform architectural and social space” in different parts of New York City. The architect says:

> “The membrane as a semi-permeable border between public and more private space and liken its use to public theatre. Another advantage of the scheme is that the bubble can be squeezed into available space where our van parks.” (Siegal, 2008).

Figure 5.25: *SPACEBUSTER transitional shelter in inflatable structure (Siegal, 2008).*

Inflatable structures in emergency sheltering for post-earthquake scenarios can be an efficient option because of the speed of erection. Generally, with inflatable or pneumatic structures emergency services are able to provide many emergency shelters in short time. However, this kind of emergency shelter can be in different types with advantages and disadvantages. For example as stated above these structures can be filled with different materials such as air, water, soil and. Inflatable structures with air can have a very quick erection mechanism similar to the erection mechanism of emergency air jackets in airplanes.

This research as an example of the application of pneumatic structure in emergency shelter can mention "Concrete Canvas" by William Crawford and Peter Brewin in 2003. Both of these inventors have a background in industrial design from The Royal College of Art. The mechanism of their innovation was to inflate a balloon and cover the balloon with prepared concrete. Finally, between 10 and 12 hours, their structure is ready to use (Sinclair et al., 2006).

This concept comes the Quonset hut used by British troops during the Second World War.[68] The difference between concrete canvas and the Quonset hut was the application of pneumatic structure, which makes the emergency shelter quickly erectable. This emergency shelter has four steps. The first step is delivery, secondly hydration, then, inflation and the final step is setting up the emergency shelter.

Deliver → Hydratio → Inflation → Setting

Diagram 5.2*: Process of concrete canvas in pneumatic structures.*

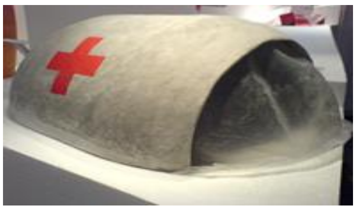


Figure 5.26*: Concrete canvas in pneumatic structures.*

This research with all of its advantages and disadvantages does not apply this type of inflatable structure as a structure option for emergency sheltering. It cannot be an efficient option because inflating equipment need power supply such as electricity, which in post-earthquake scenarios with possibility of damaged power infrastructures

[68] The Quonset hut is a very light prefabricated structure, which needs to get dry in a day. In addition, the US army used this emergency shelter as a field hospital during the war in Vietnam (Pursch, 1976).

and its not available first few hours. Secondly, it needs special equipment, such as air pumps to keep the structure inflated regularly which might not be available in different locations. Thirdly, through time the air pressure of the structure would decrease. In addition, air pumps are not familiar equipment to the public. Totally it is not an efficient option for mid-term temporary sheltering in post-earthquake areas.

5.8.3 Telescopic structures:

The third group of surface deployable structures in this research is telescopic structures, which has been tested in emergency sheltering. this structure type because of the similarity to telescopes in science and engineering, is called a telescopic deployable structure and it is a familiar erection mechanism in public. In these types of structure every object of the structure, which is usually a pipe, is able to move inside of another object and can be erected as much as required.

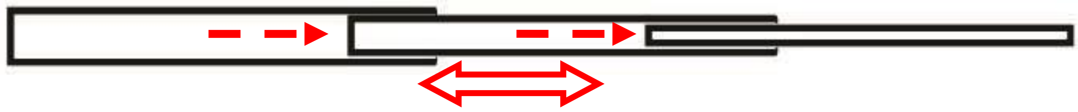


***Figure 5.27**: Mechanism of deployable telescopic structures (By author).*

Telescopic structures are more efficient to save space in comparison with other types of deployable structures because in the folded position the result is only one object. Therefore, it would facilitate erecting, folding and lead to easy transformation. This type of deployable structure usually would be used with a different type of deployable structure. For example, in umbrella structure the main tube usually is in telescopic deployable structure and branches are in umbrella mechanism. This research uses this type of erection and folding with other types of structure in prototyping, which is expanded in the portfolio page 38. (x ref)

5.9 Chapter conclusion

This research in structural design identified different structural options that have the potential to be implemented in emergency sheltering. As expanded in previous chapters, this research aimed to simplify erection mechanisms for survivors to erect their shelters by themselves with no technical skills and has conducted different workshops to test their efficiency.

This chapter started with an explanation of the role of cultural design in the sheltering process during the disaster response cycle and how research has aimed to improve the quality of life by considering cultural design in mid-term sheltering. different local tribal forms such as Kapar which have been concerned in the Literature Review have been selected as concept for structural form.

Different earthquake responses in different countries show that emergency sheltering does not engage with cultural design during short term sheltering. However, with the increasing length of settlement in shelter, the importance of cultural design increases and survivors after receiving their immediate needs in post-earthquake scenarios, become engaged with cultural issues and they try to improve the quality of their life through different possibilities. For example, in Haiti they upgraded their emergency shelters with waste materials or in Bam survivors upgraded their shelters with palm leaves because of the heat. Therefore, this research in portfolio proposed different low-tech technical methods to install palm-leaves in top of their delivered emergency shelters if needed. Palm-leaf is a characteristic material option in building industry around Persian Gulf (x ref)

In addition, this chapter with consideration on structural designs and specifically erectable/ foldable structures, designed its own structural design diagram for emergency sheltering (x ref) which covered architectural and engineering factors. This structural design diagram for the first time considers new issues, such as positive approach to global warming, sustainability in material options, energy, structural options. Public engagement in shelter preparation is another important factor which develops this research. Therefore, different workshops have been conducted to evaluate level of simplicity of erection in selected structural options.

In a section that is called Public engagement in research, the potential of survivors was discussed to be applied to the erection of emergency shelters. This section was followed by different methods related to the simplification of emergency sheltering such as the application of lightweight materials to maximise public engagement. Generally, this research, focused on deployable structures with engineering focus for a better understanding and to simplify the process for survivors.

In the second step, this research started investigating the typology of structures through history from ancient times until recent years were considered to identify all types of deployable structures, which have the potential to be implemented in emergency sheltering.

All types of deployable structures were identified by their shapes including surface and strut. In the next step, different types of deployable structures were categorized by their erection mechanisms and finally every erection mechanism was named by familiar names from instruments, which can be found in daily life and utilises their mechanism such as scissor, umbrella, accordion. For instance, the scissor mechanism that even school children were using during experiment under control of their teacher. Finally, it shapes a new table.

	Strut deployable structures	Scissor-hinged mechanism
		Umbrella mechanism
		Accordion mechanism or Folded structures

Deployable structures	Strut deployable structures	Inflatable or Pneumatic structures
		Telescopic

Table 5.4: *Categorizing deployable structures with an architectural focus (By author)*

This table as an output of this chapter with an architectural focus on emergency sheltering. This table covers all types of deployable structure types which have been concerned in engineering table (ref) but with architectural focus. Furthermore, it explains in a simple way that can communicate with people which develops public engagement in erecting emergency shelters.

Taxonomy sheet from portfolio HERE

The main concern of this research was to design a sustainable self-erection emergency shelter and it can occur only through the implementation of specific structural options. Self-construction emergency shelters are one of important development of this research. It affects the disaster response cycle, simplifies and accelerates the disaster response cycle in post-earthquake scenarios. Secondly, emergency NGOs can save their budget for training, transporting and the living cost of volunteers in a post-earthquake scenario. All of the prototypes of this research in different structural options were tested and evaluated by different age groups through firstly school children, secondly university students and finally, people with no architectural education. After each workshop and testing, the prototypes which had weaknesses were improved. The optimum choice is selected out of different prototyped shelters. The output of these workshops are documented and presented in Volume B.

Another development in terms of structural design for emergency sheltering is flexibility and possibility of extension much as needed. Extension of existing tents is not possible and each camp in the Bam post earthquake times consisted of different number of single tents. The modular design and extension of units is possible in the optimum choice of this research. Technical information of extension is provided in the portfolio and it demonstrate how emergency shelters can be connected to each other to be a bigger unit for families with more family members.

Structural options is this chapter are investigated and optimum choice is selected. In next chapter these structural options get closer to prototyping and physical model. An efficient prototype in this research should go through an accurate material selection.

Other factors, which affect efficiency and the quality of emergency sheltering are the material of shelters. The next chapter of this research will expand on the research approach in the material selection, the methods of material selection, appropriate material options and will evaluate emergency sheltering under a specific strategy.

Chapter 6
Material Design

For emergency sheltering

6.1 Introduction

People have used different natural materials and methods for sheltering throughout history but with the industrial revolution, traditional methods for using materials have been minimized in comparison with previous centuries and with development of technologies, technological materials and methods appeared. Smart materials such as lightweight or colour changing material are recent example of these innovations and developments in material science (Ritter, 2007).

> “We are standing at the threshold of the next generation of buildings: buildings with various degrees of high technologies, which are extremely ecological in their behaviour through the intelligent use of functionally adaptive materials. Products and constructions are able to react to change in their direct or indirect surroundings and adjust themselves to suit.” (Ritter, 2007:54).

At the same time, architects and designers with the implementation of material technologies are developing a new generation of products and buildings (See section 5.8.2). X ref

This research designed a different range of creative sustainable emergency shelters in different aspects such as low cost and environmental-friendly. The key point for this research is sustainability and material science play an important role in designing self-erection emergency shelters for survivors. Therefore, the research proposes that technology should not lead to complexity. A self-erection emergency shelter is one of the most important developments of this research. In addition, between two choices of simplicity and technology, simplicity is prioritised. However, in some cases the application of technology causes simplification in self-erection emergency shelters but has cost effects on the final price. Therefore, it is important to balance between these two items.

This chapter considers materials of the existing equipment for emergency sheltering and discusses about the advantages and disadvantages of those materials. Then application different materials are discussed. This chapter evaluates sustainable materials in emergency sheltering for post-earthquake scenarios. Also it introduces concepts of sustainable materials in emergency sheltering and the effects of those materials tested in prototypes with a scale of 1:1. Finally, this chapter discusses the role of sustainable materials in the development of emergency sheltering and introduces methods for a sustainable approach in the short term and long term temporary sheltering.

The research considers and evaluate different material options to make a balance between technology, cost, sustainability and environmental-friendliness. This balance is achievable through experimenting, prototyping and testing. Volume B documents all of these experiments.

The research in this chapter considers local traditional materials and methods in emergency sheltering. Secondly, it introduces innovative materials and methods with the potential of implementation in emergency sheltering. Furthermore, this chapter discusses about experiences of architects who are famous for application of unexpected materials such as Shigeru Ban as a paper architect (McQuaid, 2003) and Simon Velez as a bamboo architect (Vegesack et al., 2000).

6.2 Research Lightweight Material Selection

Lightweight material selection depends on different conditions such as geographical locations. It should be mentioned that, in terms of material selection for emergency sheltering, performance is given to lightweight materials because an efficient emergency shelter should be easy portable and light to erect. Secondly selected structural option should be construable with selected material option. For example, strut deployable structure cannot be constructed by cardboard. Thirdly scale of the model is linked to the selected material option. For example, surface structures in scale 1:100 can be constructed with paper but scale 1:1 should be constructed by thicker cardboards. All experiments of prototyping with paper and cardboards are documented in Volume B

There are different issues which are liked to efficiency of sustainable emergency shelter. An efficient lightweight material option makes emergency shelter more efficient and safer. One reason of less human loss in rural areas in Bam earthquake was application of local lightweight materials such as hasir, which is made by palm leaves while in urban areas because of application of wrong construction methods through concrete or steel post and beams number of human losses were higher (Fallahi, 2008).

Literature Review identified the gaps in term of materiality in emergency sheltering. for example risk of fire during living in tents (x ref) or upgrading tents with secondary materials because of rain (x ref). There are many examples in previous chapter related to emergency sheltering such as concrete canvas (x ref) which are high cost in comparison with tents. Therefore cost play an important role for local authorities and NGOs to supply emergency shelters. With all of the identified advantages and disadvantages of materials in existing emergency shelters, research material selection diagram for emergency sheltering are shown below. All material options of this research should pass through this diagram for emergency sheltering. This diagram is the result of considering existing emergency shelters, architect’s brief in the structural design diagram (x ref) and the lightweight material diagram in the Literature Review (x ref).

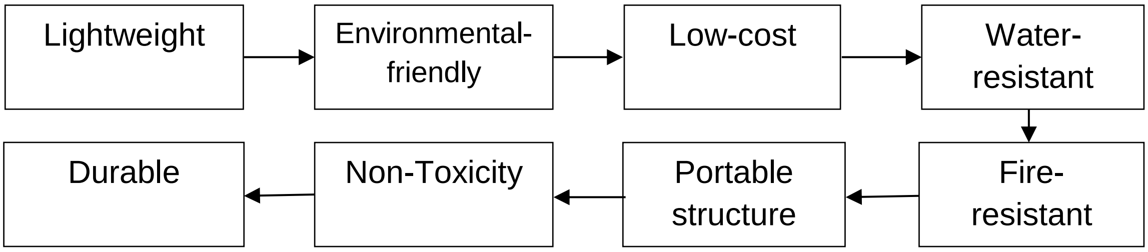


Diagram 6.1: *Research factors for lightweight material selection in emergency sheltering (By author).*

The research applied environmental friendly material options as input materials for prototyping and materials with the potential of bio-degradability as output material options including cardboards and palm leaves. This strategy directly improves the development in sustainability and it leads to less environmental toxicity[69].

The experience of the author in using the existing emergency shelters during the Bam earthquake shows that the available lightweight materials in the actual emergency shelters should be affordable and functional in terms of cost and water/fire resistant, but use of conventional materials such as tarpaulin in the long-term is not efficient in midterm and long term. In addition, survivors had to replace or upgrade their shelter with secondary materials if they have to stay for a long-term period in their shelters.

Figure 6.1: *Shelter in Bam show tarpaulin sheets were covered or replaced for long-term use (Ref: www.mojepishro.net Access date: 25/06/2015)*

During sheltering process in the disaster response cycle, the importance of sustainable and efficient materials in terms of cost, energy saving and transportation increases with length of settlement and becomes important as the settlement period gets longer.

[69] Environmental toxicity is a science of evaluating and preventing the effects and pollution of chemical materials in our environment. It challenges different sciences and engages industries to the protect the environment.

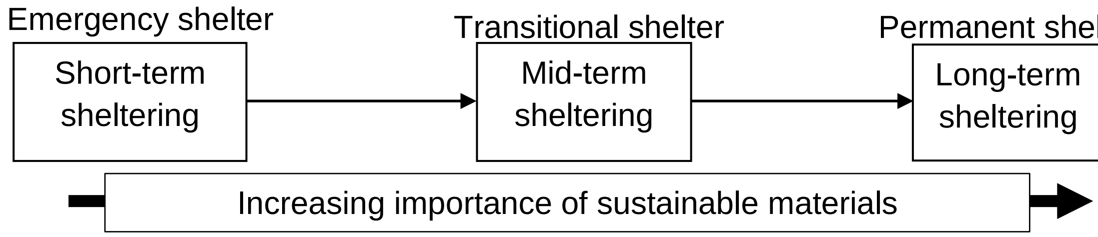


Diagram 6.2: *Importance of material selection in length of stay (By author).*

There are different factors in post-earthquake scenarios that affect survivors during settlement in emergency shelters. Depending on the disaster received countries economic welfare, some of the survivors would stay longer in emergency shelters. In some cases such as Haiti emergency shelters have become permanent shelters. In Haiti living conditions in tents after seven years conditions do not correspond to minimum of health, safety and security requirements. Therefore, this chapter provides possibility of upgrading designed emergency shelter by secondary materials because of two reasons. Firstly, those poor people who stay longer in emergency shelter can upgrade their tents with another materials which this research calls it secondary materials. Selected secondary material options depend on climatic conditions. Secondly, it improves sustainability in emergency sheltering in short-term and long-term.

UN strategy for emergency sheltering seeks a sustainable approach to material selection (Gostelow, 1999). Especially in longer-term use, sustainable design and cultural design become more important. Therefore, with evaluating situation in the Bam earthquake which survivors had to live nearly six months in emergency shelters and they experienced extreme cold and hot weathers (x ref), this research divides proposed material options into primary and secondary options, for short and long term temporary sheltering.

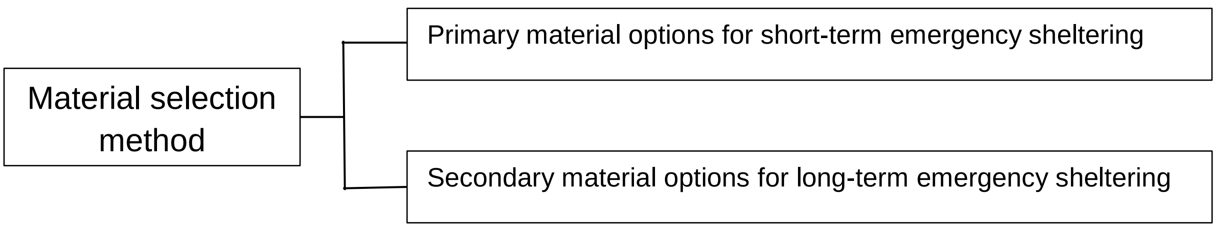


Diagram 6.3: *Material Selection for sustainable emergency sheltering (By author)*

Experience shows that after earthquakes countries including Iran, receive national and international responses including emergency shelters. In Bam, local authorities in charge of crises were responsible for relocating survivors from an emergency shelter to a transitional shelter. The length of this relocation is different in countries. In some developing countries such as Iran, local authorities would not be able to provide transitional sheltering quickly. Therefore, survivors have to stay for a longer period in emergency shelters than planned. Survivors of the Bam earthquake were living in their emergency shelters for 7 months that tents are not designed for such use. Delivered tents were designed to use up to 2 months and then move them to porta cabins in post-earthquake scenarios. Those porta cabins were designed for up to 6 months use but some of survivors stayed in porta cabins up to two years because of different reasons (see section age e Bam reconstruction). Settlement more than designed lifetime affect the quality of life, form and function of temporary shelters. Therefore, this research explored the possibility of upgrading emergency shelters with secondary materials, which are readily available.

Material selection for emergency sheltering involves various factors. For the first time this study considers material options for the long and short time uses to apply more sustainability in emergency sheltering.

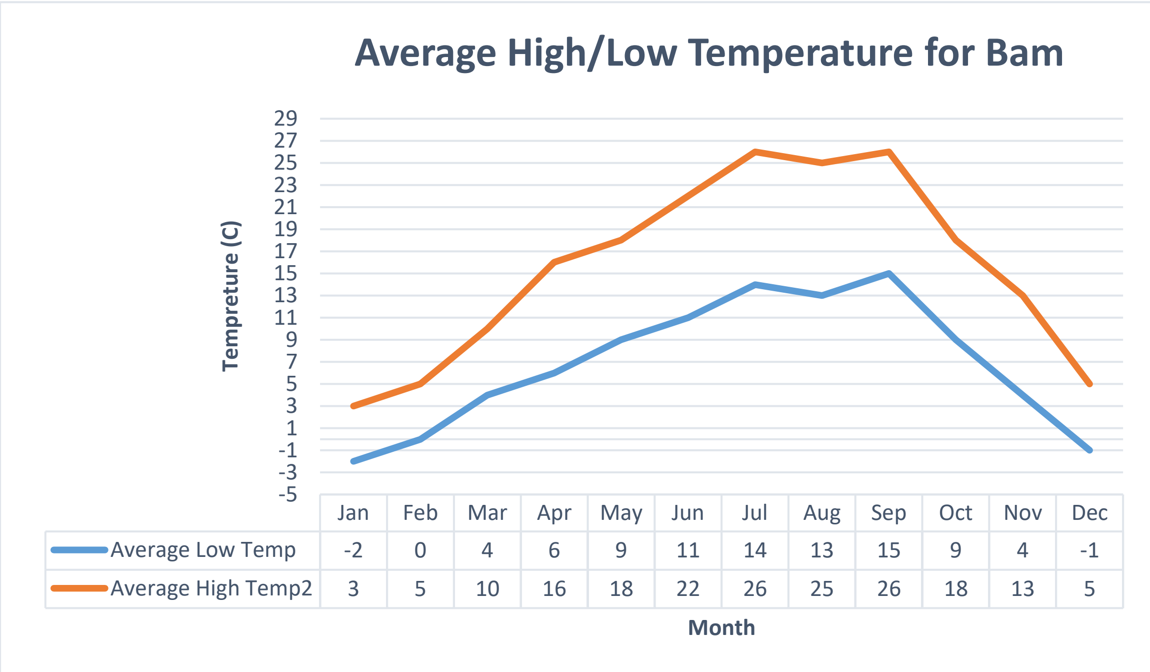
Primary material options for emergency sheltering should be available and familiar globally, lightweight to transfer, low cost, degradable, recyclable and sustainable for a short period. Secondary material options, depending on economic strength of the country where emergency shelters are going to be delivered, can be in local, low-tech or high-tech material options. This material selection method in the long and short-term period causes flexibility and more sustainability in emergency shelters in comparison to the existing materials of emergency shelters. For instance, survivors in Bam used palm leaves to cover their tents to protect it from direct sun rays and heat. This action improved life quality in hot and dry climatic conditions in Bam during summer time. Furthermore, it affected on sustainability because they used less energy for cooling. In the other side survivors used different available insulations and polythene sheets to cover their tents during winter time.

Generally, survivors eat, sleep, and recover in the same single space of emergency shelter. Selection of efficient material options improves efficiency including quality of life conditions and simplifies self-construction emergency shelters.

In addition, secondary material options in the form of double layers panels could be applied. Summer time designed emergency shelter would be upgraded by characteristic local materials such as palm leaves and winter time would d be upgraded by available local insulations. It can be industrial product from Bam such as rockwool or can be natural such as wools which is low cost and is available for Persian carpets or other purposes.

The graph below shows highest and lowest air temperature in Bam over a year, the lowest being -2 in January and -1 in December. The Bam earthquake happened in December but emergency services delivered normal tents in different sizes covered by tarpaulin and few days later electric heater (Figures 1.7, 1.8, 4.5, 4.6, 4.27)

Therefore, this research for short term emergency sheltering concerns available local insulation material options to protect survivors from cold. This research selected different material options for this purpose, which are expanded in this chapter (x ref). Technical details are provided upon in the portfolio how to install insulation materials (x ref). Designed emergency shelter consists of main material options and the secondary material options to improve life conditions in different climatic conditions.



Graph 6.1: *Average High/Low Temperature for Bam over a year (Ref:www.worldweatheronline.com, Access date: 16/05/2015)*

Research approach to Disaster Response Cycle is to manufacture shelters before the earthquake and deliver emergency shelters in primary material option by emergency NGOs after earthquake. Survivors can upgrade their emergency shelters by local sustainable materials. Designed emergency shelter become more efficient for short term and long-term use. However, this research considers energy and environmental efficiency in longer-term use in comparison to the existing emergency shelters.

> “One approach to making buildings insensitive to certain external influences, for example so that they can withstand extreme conditions is to use particularly durable (resistant) materials and products. Another approach is to use materials and products, at times even constructions, which are able to repair themselves, change their function or strengthen themselves.” (Ritter, 2007).

This approach for designing emergency shelters for short term and long term sustainability has been applied for the first time as most latest emergency shelters were considered in previous chapter (x ref). Different sustainable materials and methods are considered in this chapter. This research after prototyping and experimenting had to fail using some material options. For example, this research was considering to apply timber or plywood for strut deployable structure. For prototyping in scale 1:20 plywood and timber were efficient material options but for those materials didn't work for scale 1:1. This chapter explains all of the experimented and considered material options but majority of material options are not selected for prototyping.

Accurate material identification and implementation in emergency sheltering affects energy saving, ease of transportation and facilitates Disaster Response Cycle for emergency services. All of these possibilities including lightweight material options, which have the potential to be implemented in emergency sheltering, were selected for this research. Different sustainable material options are selected through experiments in workshops, prototyping in different scales, interviewing material technicians and experts in different institutions (x ref) and investigating other similar researches (x ref) to identify and apply efficient material options for this research.

There are different approached to select a material for emergency sheltering. these approaches are:

6.2.1 Physical shape: Emergency sheltering can be approached by creative designs to facilitate the disaster response cycle. As stated before a new generation of buildings are appearing with the development of technologies incorporating structural and material sciences. The experience of the author as an architect in the building industry and workshop experience show that the material of shelter should be in different physical shapes for different reasons such as place of implementation, methods of use and the materials as parts of the build. This research develops designs that can respond dynamically to shelter provisions and changes in need as identified by Ritter.

> "Depending on design and their passive and active structure and components, materials are able to react reversibly to their surroundings over a long period of time" (Ritter, 2012:42).

Throughout time, properties of some materials might change because of environmental reasons and not perform efficiently. For instance, as figure 4.16 shows survivors because of deformation of shelters during time had to upgrade it with secondary material options. In the long term, some materials might even have reversible and negative effects. For example, some material options such as polythene are not easy degradable and it leads to environmental toxicity.

Physical shape of every single part of a model play an important role in function including stability and weight of models. The personal professional experience of the author in the building industry shows some geometrical shapes such as the honeycomb, improves efficiency to make lightweight structures with effective engineering consideration. However, other shapes and forms might have different advantages and disadvantages. The research implemented these engineering methods through lightweight prototypes. As the figures below (Figure 6.2) illustrate, this research applies hexagonal geometric shapes to design erectable/foldable emergency shelters. This method is applied in each strut as well as fabrics for the outer layer of emergency shelters.

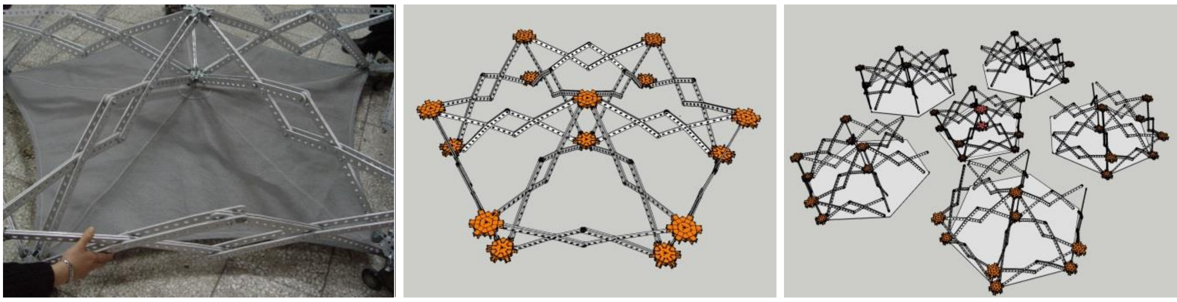


Figure 6.2: *Example of prototyping and implementation of hexagonal geometrical shapes to make a lightweight structure. Hexagonal geometry or honeycomb shapes are the usual geometric shapes to make lightweight structures. (By author)*

Cutting honeycomb geometrical shapes in structural elements is a method used by civil engineers to make lightweight structures. In addition, it makes stronger posts and beams in buildings.

6.2.2 Function: different materials because of different properties and features have different functions. Lightweight materials in this research play an important role in efficiency of emergency shelters. It is important that this research separated the function of the selected materials for short and long term. Through the research approach, this chapter applies material options, which are familiar globally such as cardboards with specific function for a short term and applies secondary material options which are available locally with different functions for a long term.

Emergency shelters should be efficient to be able to operate in all locations and it is directly linked to material functionality. For instance, delivered emergency shelters in Bam could be prefabricated from cardboard factories. In the next step survivors such as survivors in Bam and Baravat or other villages around this area would be able to upgrade with characteristic palm leaves for hot conditions or sheep wool for cold conditions. This research prototyped and tested form and function of the selected material options which are expanded in this chapter from the most familiar and simple option with the potential of implementing it in emergency sheltering in Bam.

6.2.3 Efficiency: Efficiency of material options for emergency sheltering can be considered in different areas such as transportation, energy efficiency, and the potential of materials to be cut as panels or struts. This research because of focusing on first few hours of sheltering, when there is minimum life requirement, specific material options play an important role. These material options should be efficient in all aspects such as energy, cost, environmental-friendly.

Implementation of the existing lightweight materials in emergency sheltering such as petrochemical materials have a positive effect in transportation and cost. However, it is not efficient in the long-term use and it is unsustainable in terms of energy, materials, eco-friendliness and most importantly needs technical skill to install these materials to the structure of the existing emergency shelters. As expanded emergency NGOs need to send trained volunteers or train survivors to erect in the post earthquake areas. However, application of readily available materials which are sustainable reduces transportation, costs and maximises sustainability. Some characteristic traditional materials are available in Bam such as palm leaves. This chapter counting these material options for designed emergency shelters in the Bam post-earthquake scenario as main material option.

6.3 Sustainable developments in material design for emergency sheltering:

"The concept of sustainable development is an attempt to combine growing concerns about a range of environmental issues with socio-economic issues."[70] Sustainable development is a big issue and it covers various areas such as material science, energy, CO_2 emission. Some international manifestos and regulations' affect future developments in different countries.

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission Report, 1987).[71]

The application of artificial materials and new "High–tech materials"[72] (Schödel, 2008) such as composites in architecture, has advantages and disadvantages. Some materials, because of their chemical properties cause long-term degradability or toxicity. Therefore, the application of these types of materials cause negative effects on the environmental challenges such as global warming and climate change. Moreover, these are against the contemporary global approach in sustainable development, which was expanded upon earlier.

Generally, this chapter concerns different lightweight materials but uses sources of materials that are readily available as a priority because it has many advantages. For instance, this research applies palm leaves or sheep wool for upgrading emergency shelters in the Bam earthquake. Both material options are readily available in the Bam. Palm leave as expanded in (x ref) is a familiar and characteristic material option in

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[70] HOPWOOD, B., MELLOR, M. & O'BRIEN, G. 2005. Sustainable development: mapping different approaches. Sustainable development, 13, pp.38-52.

[71] The Brundtland Report mostly talks about development related to economy but in the author's opinion it is more general to cover economically and environmentally.

[72] The most advanced technology available.

Bam and sheep wool because of famous Persian Carpet industry is available and familiar material option. In addition, as stated before, there are many methods that have arisen from research institutions around the world, which was expanded on material science and sustainable development on the subject. This research contributes to the knowledge through positive approaches to the global sustainable strategy through emergency sheltering.

This research designed sustainable emergency shelters for post-earthquake scenarios, which acts individually. It means it provides the possibility of self-erection and potential of setting up in the post-earthquake scenario by survivors in every geographical and climatic condition.

Regarding sustainable development, it should be mentioned that sustainable development in material science is linked to structural science. Therefore, development in emergency sheltering is linked to the development of structural and material sciences. Hence, after identification of appropriate material options, for more efficiency the research has focused on materials of structures in emergency sheltering. The important point in this case would be that the material of structures should have the potential to be upgraded through secondary material options for long-term sustainability. Therefore, as presented in the portfolio pages (x ref) 13, 40, the material of structures is in water proof cardboard; different material options are expanded in this chapter.

6.4 Material options for multi-time use of emergency shelters:

The research designs different range of sustainable emergency shelters with recycled and recyclable local materials such as waterproof cardboard and recycled wood products to become more environmental-friendly in comparison with the existing petrochemical materials. Upgrading emergency shelter in this research causes adaptation in different conditions. Therefore survivors will be able to reuse it for different purposes. In addition, as expanded in Chapter Three, survivors in Bam reused their tents for other purposes after transferring to their private lands and close to their collapsed buildings. They were still using their tents after moving to porta cabin and they were using it as storage. Multi-time use causes less manufacturing of temporary shelters, less energy consumption, less material use and more sustainability.

Mid-term and long-term use of the existing emergency shelters causes change to the form and function of the tents and in the long term, causes many other problems such as collapse and waste of energy. The implementation of sustainable low-tech traditional materials such as palm leaves or technological sustainable materials such as water and fire resistant recycled cardboard are proposed in this chapter for prototyping. Portfolio illustrates the process of prototyping with different material options.

6.5 Sustainable material selection for emergency sheltering in this research

Literature Review identified sustainable methods from different industries. This chapter discusses and prioritizes sustainable methods for material selection in emergency sheltering. Identification and evaluation of those sustainable methods are expanded below. Sustainable methods are introduced with differences in terms of sustainability to minimize use of natural resources and raw materials. This chapter prioritizes these methods for more efficiency in material science. These sustainable methods come from a scientific journal (MRS, April 2012) but the diagram below is an output for emergency sheltering with deep consideration to the Emergency sheltering. In addition, during prototyping the diagram below was a base for material selection. The research contributes to the existing knowledge with introducing sustainable material selection for emergency sheltering. Input materials for prototyping emergency shelters and sustainable output materials after emergency sheltering have their own priorities.

The priorities of sustainable material selection when prototyping emergency shelters are 1- conservation of materials, 2- replacement, 3- repositioning of materials and finally 4- recycling. The explanations of these methods follow:

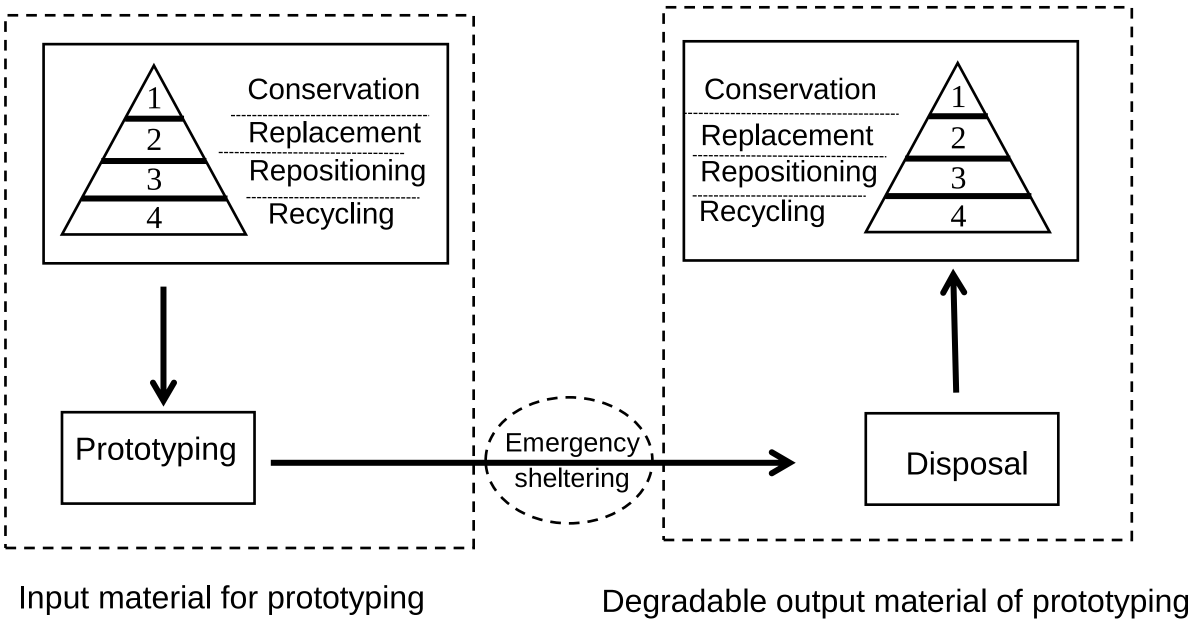


Diagram 6.5: *Sustainable material selection method for emergency sheltering.*

6.5.1 Conservation: Conservation for this research is; after scrapping an item different useful parts of it, without changing their form and function, can be used for second time. This research uses the same method for a sustainable emergency sheltering as a priority. Therefore, it does not need energy, raw materials or technical skills for manufacturing, cutting and resizing. In this research, every emergency shelter consists of different parts such as panels or struts and insulation materials for long-term use, which are expanded upon later in the text. This method is the most sustainable method for modelling and prototyping.

6.5.2 Replacement: The second sustainable method for emergency sheltering is replacement. In replacement, any panels, struts, or similar waste objects with similar physical shapes which could be from other industries can be replacement parts for a new emergency shelter. For instance, this research for prototyping strut deployable structure type 2 in the portfolio used different pieces of scraped canvas from broken umbrellas which were in polygon shape with 6 sides (X ref). Therefore, this method consumed neither energy, technical skills, expenses nor any reshaping or resizing material. This replacement method, in comparison with conservation is still one of the most sustainable methods, where there is no need for raw materials and energy to reshape. Therefore, it saves time, energy and materials.

6.5.3 Repositioning: Repositioning for this research is a method where a part with a specific function would be moved to a new function but during relocation it should be reshaped physically to suit the new function.

In the case of emergency shelter prototyping, waste objects from other industries can be reshaped and relocated to be used as panels or struts in an emergency shelter. This method was applied for the prototyping in the figures below (Figures 6.4- 6.6). In the workshop, repositioning was applied for more sustainability rather than implementing new cardboard.

The first step of the prototyping process started where the author inspected all the waste materials every week in different buildings. Waste cardboards, which were white board boxes (Previous function) were selected and collected all. The second step was reshaping the waste cardboard at the workshop to five different shapes and finally used them as panels (new function) in prototyping.

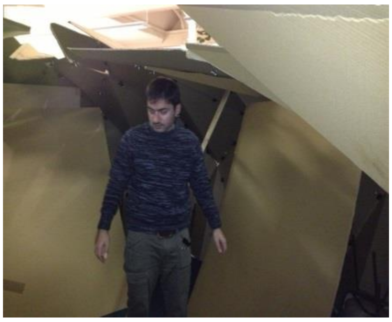


Figure 6.4: *Collecting waste cardboards (By author)*

Figure 6.5: *Prototyping in actual scale (By author)*

Figure 6.6: *repositioning in workshop (By author)*

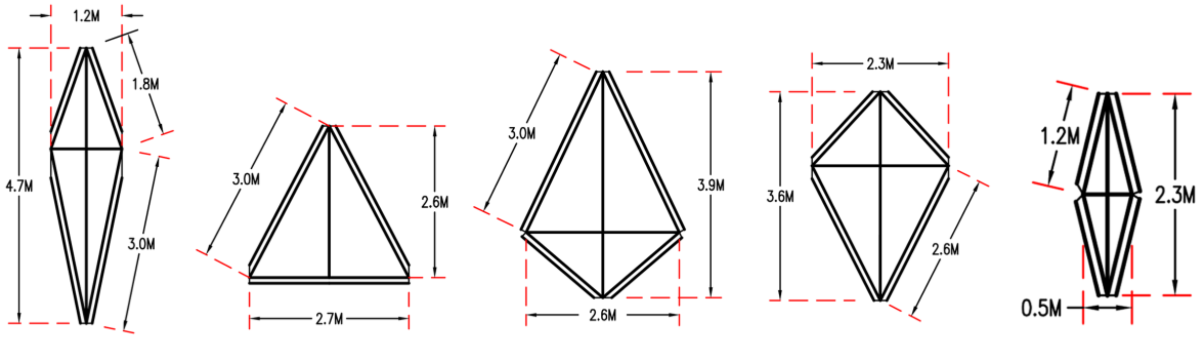


Figure 6.7: *Repositioning of cardboards for a new function (By author)*

The previous experience of the author in the building industry demonstrate that during reconstruction of existing houses this method is more popular with builders and constructors because changing the physical shape of the first item with minimum cost provides many possibilities for it to be used for a second or third time. However, repositioning needs energy and in some cases technical skills, but it is still cheaper than recycling. Architects and project managers during reconstruction should decide on the location of the implementation because it requires technical skills. Implementation of waste materials in emergency sheltering would be the same because repositioning requires technical skills to reshape and apply in emergency sheltering. It is important to mention that manufacturers are responsible to prefabricate emergency shelters and survivors are going to erect the shelters only.

6.5.4 Recycling: Recycling is a sustainable methods where waste materials should be collected. In the next step, by application of a specific process new materials can be produced. After recycling process, output materials usually have the same property as the input materials. However, depending on the recycling process new products could have similar material property or have a different quality. Therefore, output materials can be manufactured with different physical shapes and technical performance.

Materials such as cardboard, which is a material option for prototyping in this research, are degradable and placed in a short term recycle system. Recycling has many advantages and disadvantages. The advantage of recycling is; the sustainable method where a material, which is non- repositionable or non- replaceable, could be recycled at the final stage. Its disadvantage is; it requires technology, energy and time in comparison with other sustainable methods which is not available in all locations.

Prioritizing in this research caused selecting more sustainable materials for emergency sheltering. Material sustainability and preventing environmental toxicity after disposal in emergency sheltering would be another development in this field that has not been considered before in emergency sheltering. For example, aluminium is a lightweight material for prototyping in emergency sheltering. Workshop experience demonstrates that implementation of aluminium panels for surface deployable structures cost more in comparison with cardboards, plastic sheets and other low-cost primary material option that are presented in this chapter.

As discussed above sustainable material selection in this research, offers four methods of sustainable material selection. In this diagram recycling is the last option. Generally, developed and developing countries with sustainable technologies have more opportunity to recycle materials. On the other hand, poor countries with less or no recycling technology have the possibility to implement other sustainable methods such as replacing, repositioning and conservation methods.

Public engagement and changing of the public attitude towards recycling in different societies is very important in sustainable development. It needs cultural education to change their behaviour. Large-scale public engagement needs government, local authorities and technologists to develop national or world challenges or developments (Timlett and Williams, 2008). This research rather than dependency to cultural education in a post-earthquake scenario or training survivors how to erect their emergency shelters, applied simple and familiar erection methods. It applies local forms and local materials which exist in public domain to design sustainable self-erection emergency shelters. This approach maximises public engagement in shelter erection.

6.6 Sustainable materials options for emergency sheltering

Emergency shelters would be more sustainable through material options, which are lightweight, durable and degradable in comparison with the existing materials for emergency sheltering. This research identified sustainable lightweight materials for prototyping.

In recent years, several types of shelters have been used as emergency shelters in post-earthquake scenarios such as Global Village (ref) and Concrete Canvas (ref) which as statistics shows Emergency services still prefer to apply low cost and low tech tents instead of Global Village shelter or Concrete Canvas. However, there are some successful examples such as Shigeru Ban who uses paper tubes in emergency sheltering (Ban, 2006). A creative and efficient prototype as an immediate architectural need for the disaster response cycle depends on the output of the research in material design and structural research. These two issues are linked together. It means this research implemented appropriate sustainable lightweight deployable structures, in terms of energy save and environment toxicity. Therefore, the material options of emergency shelters play an important role as an immediate architectural need in post-earthquake scenarios.

In recent years, many different sustainable materials such as paper tubes and non-sustainable material options such as tarpaulin, aluminium, plastic, and concrete have been applied for emergency sheltering. As the previous chapter demonstrate, the latest emergency shelters in new technology such as “Concrete Canvas “by William

Crawford can be used in post-earthquake scenarios but those examples and the mechanism of erection is not as quick as existing emergency shelters such as tents and Concrete Canvas takes 8 to 10 hours to hydrate (x ref).

Furthermore, existing emergency shelters are less concerned with the sustainability of materials, energy and environment in order to design the environmental-friendly emergency shelters. Some materials, which are expanded upon below as material options, have the potential to be implemented in emergency sheltering in Bam. Some of these material options are readily available as a main material option and some as a secondary material option for long-term use. An efficient and sustainable material for emergency sheltering should be lightweight, environmental-friendly, low-cost, water resistant, fire resistant, easy to transfer and finally appropriate for longer-term use.

Workshop experience and volunteering during Bam earthquake demonstrate that some materials such as cardboard or palm leaves can be efficient materials for emergency sheltering in post-earthquake scenarios. This research after investigating through different materials which are expanded in this chapter focused on some materials for emergency sheltering which are sustainable in comparison with existing materials. This research categorised material options for emergency sheltering in different industries such as the wood industry, paper industry, and chemical materials industry. The efficient and appropriate materials from each industry are considered below.

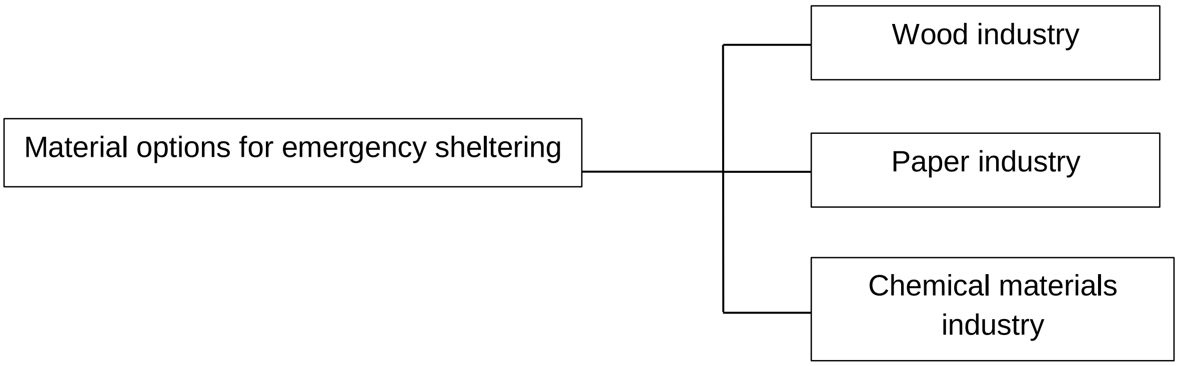


Diagram 6.6: Categories for material options for emergency sheltering (By author)

As expanded on before, this research identified material options for short and long term emergency sheltering. Short-term material options should be available and familiar globally and they would be the main material option for short term sheltering while long-term material options as secondary material options can be manufactured locally and because of their lightweight properties can be delivered easily to different locations of the post-earthquake scenario. Alternatively, survivors can upgrade their emergency shelters with proposed sustainable material options that could be available locally and at low cost. More flexibility is planned in the secondary material selection for survivors.

Out of the material options for emergency sheltering in Bam, all of the paper industry products, which are proposed below, are suitable to be implemented as primary material options. However, some material options from the wood and chemical industry were proposed to be implemented for emergency sheltering but after prototyping and experimenting this research failed to apply for emergency sheltering. All of those selected and failed material options are mentioned in this chapter.

This research is responds to short-term and mid-term architectural needs by upgrading emergency shelters. All of the environmental-friendly material options are selected for these periods of sheltering. Material options, which are degradable in long-term or causes environmental toxicity, are not selected. In addition, the availability in Bam is another important factor.

It is important to mention that this research refers all of material options to Bam for evaluation and comparison with other material options including, availability, cost, transportation and other items mentioned in diagram 6.1 (x ref). Proposed material options from wood industry are as below.

6.7 Material Options from the Wood Industry

This section discusses collected information from section 1.8.5 (x ref) Wood Industry in the Literature Review. Different readily available material options and different possibilities from the wood industry for emergency sheltering are considered. As expanded upon earlier in this chapter, there are different factors that effect on materials selection. Different materials from the wood industry in emergency sheltering are listed below. These are sustainable, low-cost, available and familiar material options, which are available in Bam. These possibilities, which are listed below, are selected through local materials for housing, which are mostly traditional materials in Bam. Local material options for housing is expanded upon in the Literature Review in the Bam section (x ref). In addition, there are some material options in the building industry, which are popular to use in contemporary architecture in Bam such as cement or technological wood products. Some of these material options that have the potential to be implemented in emergency sheltering are listed.

In addition, the author has experienced different materials and methods in the building industry as well as prototyping in university workshops during research. Material options, which have the potential to be implemented in emergency sheltering from the wood industry, are as below, could be technological products or natural material such as coconut fibre.

The research categorizes possibilities of the wood industry for emergency sheltering in two groups; including ordinary timbers and engineered wood.

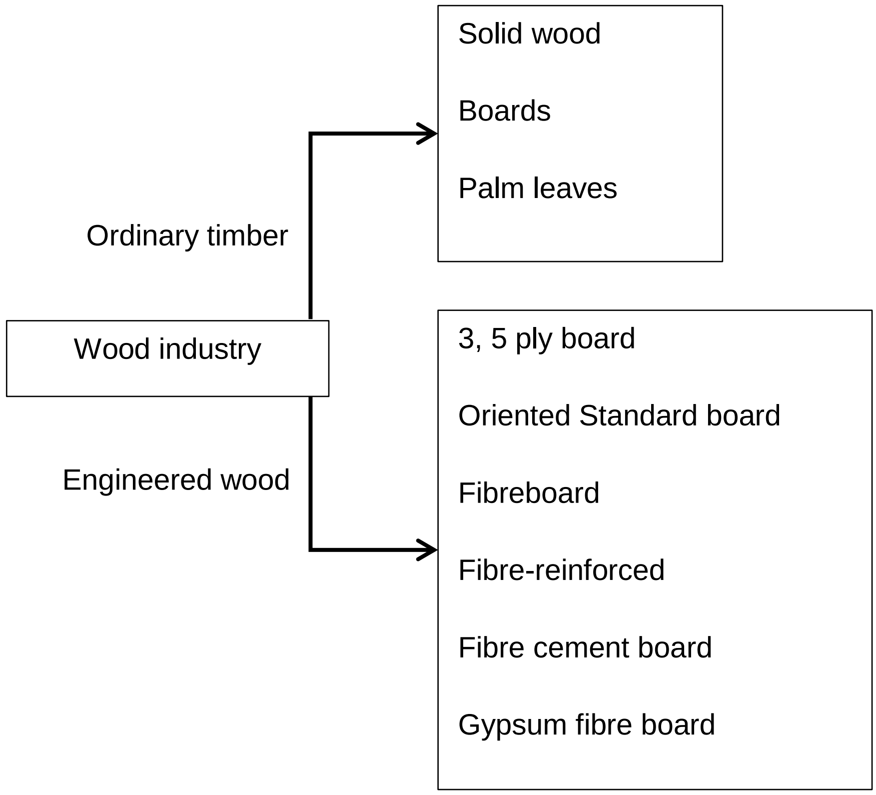


Diagram 6.8: *Categorization of material options in wood industry (By author).*

6.7.1 Ordinary timber; available materials options in Bam

The first group of material options from the wood industry are technologically basic. This type of low-tech timber is available in majority of earthquake areas including Bam. The most readily available wood type in Bam is Palm timber which has been used through time for housing. These low-tech material options which is available in Bam are as below.

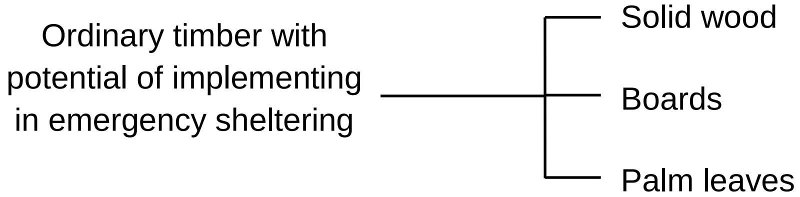


Diagram 6.9: *Material options group 1 for emergency sheltering (By author).*

This chapter depending on the structure of emergency shelters changed the physical shapes of ordinary timber to use them as struts or panels for prototyping. Generally timbers because of physical shape are more appropriate for strut deployable structures and boards appropriate for surface deplyable structures. This research experimented these material option. The output of experiment was as below. Low-tech timbers and boards were efficient for prototyping in scale 1:20 and 1:5 for strut deployable structure. As model (x ref) in portfolio shows geodesic domes in small scale were prototyped by boards but actual scale modelling was not possible and the author had to choose another lightweight materials which was aluminium (x ref). Therefore, this experiment showed that ordinary wood is not an efficient material option for strut deployable structure because the final structure in actual scale would not be stable and collapse.

Prototyping surface deployable structures with ordinary timbers including boards is possible but not efficient because experiment proved that weight of panels were not lightweight and in comparison with existing tent and optimum choice of this research which is made of cardboard is heavier. Therefore, final output would be heavy and not easy to transform.

The optimum design in portfolio is a pre-fabricated emergency shelter which will be delivered in the post-earthquake areas. Earthquake survivors do not have to cut the panels and assemble different parts of emergency shelters in the post-earthquake scenarios. Survivors should erect delivered emergency shelters through a simple erection mechanism for their temporary sheltering only. These proposed material options are listed below for prototyping before earthquakes.

Solid wood: Solid wood is generally made from common types of soft wood such as spruce, fir, larch and pinewood which when debarked are very popular in furniture making and construction (Hugues et al., 2004). However, Bam has different vegetation because of special climate conditions, which is hot and dry. Industrial trees in Bam are palm, prosopis, ziziphus and eucalyptus[73]. There are other types of trees in Bam such as orange but those are more efficient economically in agriculture not for the wood industry. Solid wood because of its popularity, availability and low cost had the potential to be used as the main material option in emergency sheltering but after prototyping and experimenting output was not efficient enough in scale 1:1.

[73] Iranian National Social Security Organization website/ Natural resources http://www2.farstamin.ir/web/darmankerman/aboutprovince/1/1

Solid wood	Unit Price in Bam	Struts for shelter (Price)
Palm	130,000R	39,000 R (1.3 USD)
Prosopis	170,000R	510,000R (17 USD)
Ziziphus	270,000R	810,000R (27 USD)
Eucalyptus	310,000R	930,000R (31 USD)

Table 6.1: *2.0m long 10mm x 300mm and price of solid wood. Spring 2015 (By author).*

Boards: Unplaned softwood boards and planks are parallel square edged materials. These types of boards are usually being manufactured in different thicknesses and sizes (Hugues et al., 2004). Boards are efficient for prototyping because there are different types of boards including thin boards which is lightweight. Secondly, boards fit into digital fabrication equipment such as lasers cutter while other materials such as cardboard do not have this possibility. For example, as the picture below shows during prototyping in the wood workshop the laser cutter plotter was able to cut 16 struts per sheet.

Figure 6.8: *Screenshot of a video during prototyping strut deployable structure as an emergency shelter with board in laser workshop (By author).*

prototyping in University of Manchester/ Laser workshop

This research experimented boards for surface deployable structures and strut deployable structures. Generally soft wood for prototyping in scale 1:1 did not work. It makes emergency shelters in surface deployable structure heavyweight and it strut deployable structures would not be stable with boards as this research applied aluminium for strut deployable structure (x ref)

Palm leaf

With architectural consideration on palm leaves as a material option for sheltering through history, this research applied it to emergency sheltering. Records show that survivors during temporary sheltering in Bam, had to cover their tents with palm leaves to cope with the heat which was the result of direct sun ray on their shelters. Therefore, it shows its potential to be used in emergency sheltering locally.

Figure 6.9: *Application of palm leaves as a local material in Bam during emergency sheltering (By author).*

As it is clear, some traditional materials, such as palm leaf, are not suitable for all climate conditions but in the case of emergency sheltering in Bam application of this lightweight, available, low-cost and sustainable material reduces expense and causes more development in emergency sheltering.

Palm leaf is a sustainable and efficient material for housing and emergency sheltering. In the northern region of the Persian Gulf application of this material is traditional and it has a character while in the north of Iran, which is more mountainous with a cold and wet climate, stones are more efficient for more sustainable buildings.

Emergency sheltering follows a global strategy and this research offers a different range of sustainable emergency shelters in surface or strut deployable structures which are made from different materials such as waterproof cardboard and recycled plastic boards or other basic sustainable materials for emergency shelters. In the next step, survivors and emergency NGOs have the possibility to upgrade erected emergency shelters with secondary material options, which could be found locally such as palm leaf for long term temporary sheltering. Application of palm leaf as secondary material option in Bam has many advantages including; it is sustainable, degradable, lightweight, environmental-friendly, low-cost, non-toxic and efficient.

6.7.2 Engineered wood; available material option in Bam:

The second group of material for emergency sheltering from the wood industry consists of wood as the main material with secondary other materials, which are manufactured with low or high technology such as 3 and 5 layers plywood. Factories and experts from the wood industry produce different products of wood with several techniques. There are four local manufacturers in Bam, which causes the building industry to use different types of engineered wood. This possibility causes different types of plywood to be low cost in Bam.

Basically, engineering methods in the wood industry leads to many extra advantages on top of the natural advantages of timber. For example, the strength of plywood with a specific type of wood and specific physical shape is more than normal wood with the same physical shape (Markwardt and Freas, 1962). Some of the material options from engineered wood, which have the potential to be implemented in emergency sheltering are as below.

Engineered wood options with potential of implementing in emergency sheltering

- 3, 5 layers ply board
- Oriented Strand board
- Fibreboard

Diagram 6.10: *Group 2 material options from wood industry (By author).*

3, 5 layers plywood: Plywood consists of three or five layers of softwood glued to each other. The thickness of plywood depends on the thickness of every single panel of soft wood layers. This type of wood with regards to emergency sheltering as a material option requires more time and energy for cutting because it consists of different layers and chemical material.

This research experimented cutting same size struts with laser cutter plotter. The physical information of the struts are provided in volume B, page 37 (x ref). Workshop experience demonstrate that glued laminated timber needs 2 times more time and more energy to cut a same size and thickness strut in comparison with a pinewood as a solid wood. Spent time for cutting same strut through 3 layers plywood needed almost 3 times more in comparison with spent time for solid wood.

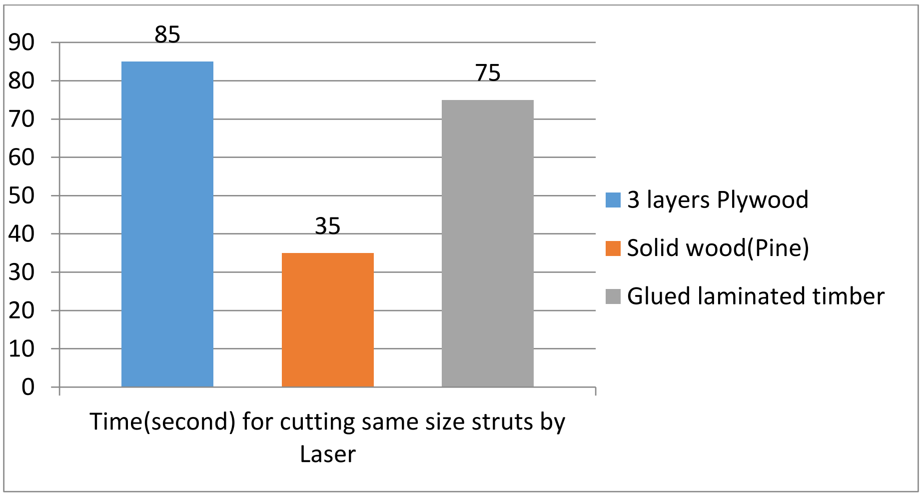


Chart 6.1: *Laser workshop statistics (By author).*

This research, considered plywood as a main and secondary material option for emergency sheltering because it has many advantages but it didn’t work in scale 1:1 and structure was not stable. Therefore, the author had to use lightweight aluminium to test strut emergency shelter (x ref). Some advantages of plywood is; it can be count as a low-tech wood product in Bam, low cost engineered wood option, the potential of conservation, replacement, repositioning and recycling because it is one of the common material options in the building industry, furniture making and is reusable for strut making e.g., after disposal. In addition, plywood is also available in different sizes and forms in the wood market in Iran. According to the Business Information Bank[74], which is private company, Bam County has 54 carpentries and timber yards. The price range of plywood in Bam is as below

Thickness	Sheet sizes	Layers	Price
6mm	2000 x 1200	5 ply	1,900,000 R (63 USD)
8mm	2000 x 1200	5 ply	2,650,000 R (88 USD)
9mm	2000 x 1200	5 ply	2,900,000 R (96 USD)

Table 6.5: *Prices of Plywood in Bam (By author).*

Waste materials in the Bam post-earthquake scenario: As expanded upon in the Literature Review, the next step after relief is landscape recovery. During the earthquake response cycle in Bam, emergency NGOs made a waiting list for reopening the roads and landscape recovery in different parts of the city. Therefore, survivors had a chance to collect waste materials to store for reuse during the reconstruction of their permanent shelters. Dr Fallahi believes that during reconstruction, 20% of building materials were sourced from survivors' collapsed houses including bricks, steel and wooden post and beams, doors and windows (Fallahi, 2008). Thus, these have the potential to be a good source for this research to improve the quality of temporary sheltering in post-earthquake scenarios.

Different types of wood were collected from different parts. For instance, as figures 6.10 show, survivors in Bam collected different materials including doors and furniture, which are made from different types of wood including timber and engineered wood. In Bam wood products including those which are made from particle or recycled wood are low cost because there are 4 local factories which produce wood products including timber and engineered wood for Bam and Kerman. Therefore, the application of oriented strand board, fibreboards and extruded particleboard and other products are efficient material options for different purposes. Generally, these materials because of their low-cost are popular material options for different purposes in Iran and Bam too.

As a result, this research recommends applying those waste materials for upgrading emergency sheltering. As mentioned above survivors save useable materials from their collapsed houses. Some of these identified material options are expanded below.

[74] http://www.asnafinfo.com

Figure 6.10: *Survivors were collecting most of materials and personal belongings (Ref: Mehr News Agency Image credit: Yunes Khani)*

Oriented Strand board (OSB): The advantage of this type of wood is it is a low-tech wood product, which can be manufactured from recycling waste wood. In addition, because of the different chemical materials and different resins used during manufacturing it becomes a waterproof board (Hugues et al., 2004).

Finally, the structure of this material option is fibrous, which makes it easy to cut. However, the disadvantage of this material option is the use of chemical materials such as thermoplastic for manufacturing, which causes environmental toxicity in the long term. This type of wood is low cost because it can be produced through recycled materials. For example, the price of a full sheet of oriented strand board sized 8mm by 1200mm by 2500mm is 700,000 Rials (23 USD). As expanded in about structure of Oriented Strand board (OSB) and different purposes to use, this material option, through, repositioning, replacement and recycling methods from waste materials in the Bam post-earthquake scenario has the potential to be implemented as a secondary material option as survivors re-use this material option from collapsed buildings or broken doors, furniture.

Fibre boards: Fibre board is one of the experimented material options in this research for prototyping. It consists of waste wood particles which is low cost. The particles are combined under heat, with or without thermoplastics or glue or other chemical materials (Hugues et al., 2004). This type of wood, because it is lightweight in comparison to other wood options had advantages to be implemented in emergency sheltering. However, this material is not water resistant and the weight of this material option increases under rain. Finally, through time it will be deformed.

This material option, through repositioning, replacement and recycling methods from waste building materials has the potential to be reused but prototyping and final output with this material option is not efficient and stable.

In terms of implementing engineered wood products in emergency sheltering in Bam, generally, timber is lower cost than engineered wood. Therefore, because of lower cost, it would be more efficient to apply one of the mentioned sustainable methods to reuse waste building material, which survivors can collect.

The experience of the author in prototyping, through different workshops including laser cutter plotter, demonstrates that there is more time and energy required to cut engineered wood products in comparison with timber. For example, struts with plywood, which is an engineered wood, consume more time and energy to cutting in comparison with solid wood. As previously stated, chart 6.1 (x ref), which is the result of workshop experience, demonstrates the differences between three material options for cutting through laser cutter plotter.

6.7.3 Engineered wood/ Composites

This group of engineered materials from the wood industry had the potential to be implemented in emergency sheltering theoretically but after experimenting and prototyping in scale 1:1 output was not efficient enough and would not be stable. It is expanded below. Most of these material options are were applied as a secondary material option in Bam because of different reasons. Firstly, they are local manufactured, which affects the building industry. Therefore, after the Bam earthquake these material options can be collected by survivors for reconstructing their permanent shelters as they did. (Picture x ref)

This section discusses about possibilities in Kerman province. Generally, composites from wood industry, include a percentage of wood and a percentage of other components or chemical materials. Kerman province in Iran is famous for Sar-Cheshmeh copper factory[75], Kerman Fajr chemical and petrochemical complex[76] and Kerman cement factory[77], which is one of the most important cement factories in the country. These factories cause readily available material options in the building industry. Kerman cement factory is located in the south of Kerman city and close to Bam-Kerman motorway. Therefore, it affects the building industry as well as the wood industry. Production of some engineered wood options such as Fibre cement board in Bam is the result of this industrial neighbourhood.

These materials usually in terms of function are very efficient. For example, these materials could be efficient materials for insulating and energy saving or fire and water-resistant shelters. Disadvantages of these materials are that they mostly need longer-term to return to the natural cycle system in comparison with ordinary wood. In addition, depending on the chemical material, it causes environmental toxicity in

[75] http://www.nicico.com

[76] http://www.fajrco.com

[77] http://www.kermancement.com

different levels. These available complex material options which this research evaluated to apply in emergency sheltering are as follows:

Engineered wood/composite options with potential of implementing in emergency sheltering
- Fibre-reinforced
- Fibre cement board
- Gypsum fibre board

Diagram 6.11: *Engineered wood/composite options (By author).*

Fibre-reinforced board: "In contrast to organically bonded wood based material, fibre-reinforced cement boards are organically bonded with cement. They can be used in the same field as wood classes" (Hugues et al., 2004:52). Implementation of this type of board in emergency sheltering has many advantages and disadvantages. The cement as an outer surface of the board makes this material fire resistant. Secondly, technical information on this type of board shows that with using cement, as a part of this material option, fibre-reinforced boards are not lightweight in comparison with other technological wood products. Technical information on fibre-reinforced boards shows that the weight of cement in each panel is one third of a wooden panel used in fibre-reinforced (Hugues et al., 2004). For example, if the total weight of the panel is 300gr, 100 gr is for cement layer and 200gr is the weight of the wooden panel as inner layer. Therefore, with the mentioned advantage and disadvantage, fibre-reinforced boards cannot be an efficient material option for long-term temporary sheltering. This chapter identifies fire resistant material options to apply in emergency sheltering because risk of fire is high. As the figure 6.11 (x ref) shows, one of the survivors' tent burnt because of using fossil fuel heater. Health and safety issues play an important role in these kinds of spaces.

Figure 6.11: *Burnt emergency shelter because of using unsafe material options for emergency sheltering. (Ref:www.varzeghanaras.blogfa.com)*

Fibre cement board: This type of board consists of compressed particles and cement as an outer layer. These boards are usually used in the building industry for partitioning and water proofing. Secondly, it is fire resistant. This material option in comparison with fibre-reinforced board would be cheaper. This chapter concerned cement board as another available engineered wood product, which is available in Bam, with the potential to be applied in emergency sheltering but after experimenting panel cutting output was not lightweight in comparison with fire resistant cardboard. In addition, sustainable methods for upgrading emergency shelters such as repositioning, replacement and recycling from waste building materials are applicable and survivors have the possibility to reuse. (X ref).

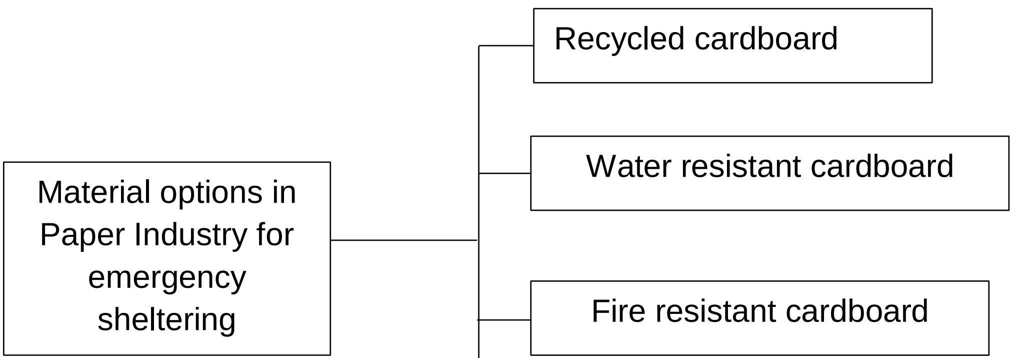
Gypsum fibreboard: “Gypsum fibre board is a homogenous board made from a mixture of calcined natural plaster and cellulose fibres. The cellulose fibres, which are primarily obtained from recycled paper, strengthen the board” (Hugues et al., 2004:53). This material needs technological equipment to be manufactured and it is not a local material in Bam. Gypsum fibreboard in Bam comes from Kerman, Tehran or Shiraz. However, application of this material option through repositioning, replacement or recycling of collapsed buildings in the Bam post-earthquake scenario was possible.

The gypsum fibre board as a material option has many advantages and disadvantages for emergency sheltering. Firstly, it is partly produced by recycled paper, which makes it more environmental-friendly in comparison with other petrochemical options. Secondly, it is waterproof but not fire resistant in comparison with other options. In addition, it is not lightweight material in comparison with applied material option in designed emergency shelter in this research. (X ref to optimum choice in portfolio)

6.8 Material Options from paper industry

This section considered material options from the paper industry and it discusses how it develops emergency sheltering. Same as other material options, which are selected from other industries, the material options from the paper industry, it should pass through the material selection diagram in this chapter(Diagram 6.1).

Out of different types of products in the paper industry, this section focused on recycled cardboards, water resistant cardboard, fire resistant cardboard and paper tubes because of the availability, production on a huge scale, low cost in the Bam in comparison with other types of material options.



The prototyping experience of the author from the beginning of the research with paper as material options in emergency sheltering shows that there is no technical equipment required to fold, mark and cut for prototyping in different scales such as 1:1. In addition, many experiments were carried out by the author regarding designing self-erection emergency shelters. Experimenting with paper as a familiar material option has positive effects on self-erection emergency shelter. Secondly, low-tech traditional skills such as shelter making with palm leaves or erection of origami are implemented to make emergency sheltering simpler. Thirdly, two experiments were conducted in order to assess the potential for public engagement with self-erection emergency sheltering. These two experiments were carried out with different age groups participants such as school children. The results of both experiments are presented in the portfolio in the form of charts. The process of two experiments are below:

First experiment: On Tuesday 26th and Wednesday 27th November 2013, 12 students from Manchester Metropolitan University aged between 17- 25 years old with no technical skills volunteered to help the author cutting panels with given physical information and demonstration. The physical shapes of the panels were in square and triangle which are familiar geometrical shapes. In the second step, students were able to assemble the panels with instruction. Finally, they erected their prototype without any instruction. The students were so excited during prototyping; the author did not expect that level of satisfaction from the student group.

This experiment and other experiments (x ref to UN competition) show the potential of public engagement in self-erection emergency sheltering. In reality in all steps of prototyping, the volunteers were excited to see the output. Figures below (figure 6.12) show some stages of prototyping. This workshop experimented cutting and assembling panels which is one-step before erection of emergency shelter. It is important to remind that the research strategy is to prototype and assemble emergency shelters before earthquake (actions before earthquake). Survivors are going to receive prefabricated self-erection emergency shelters after earthquake.

However, cutting and assembling the emergency shelters by adults with no technical skills demonstrate the simplicity of manufacturing emergency shelters.

***Figure 6.12**: Prototyping emergency shelters by un-skilled volunteers aged between17 – 25 in University. Prototyping includes cutting and assembling the panels.26^{th} and 27^{th} Nov 2013.*

Second experiment: To assess the potential of public engagement in emergency sheltering the author experimented self-erection emergency sheltering with students from St. Margaret elementary school who were aged between 9-12 years old. These workshop experiments helped them to apply their self-motivation power in different stages. The author had restriction concerning health and safety issues for the school children regarding the cutting of the panels. Therefore, the workshop organizer handed them half scale of actual emergency shelter which had pre-prepared panels to assemble and construct. The interesting point in this experiment was the school children were very excited and interested in constructing their own shelters. The figures below show their satisfaction at different stages of the sheltering experiment. However, this research is restricted to show underage students faces in images.

***Figure 6.13:** Prototyping a cardboard shelter by kids aged 5 – 10 years old from St. Margaret elementary school, Manchester, with prepared panels.*

Other workshops and tests have been conducted with different age groups by author, which are expanded in the portfolio. (See volume 2, page 28-34)

There are different activities in daily life that deals with paper products and these daily activities demonstrate the familiarity of humans with paper. In addition, some countries, which are located in earthquake belt such as Japan, have applied this familiarity. Different products from the paper industry are material options for the building industry in Japan. Additionally, the education system in Japan has regular planned prevention practices in schools to apply available lightweight materials such as cardboards to construct their own shelters. The images below (Figure 6.14) show a teacher training students how to make a shelter with cardboard boxes in Tokyo (Architect, 2008).[78]

Figure 6.14: *Three images of prototyping a shelter by school children in Japan (Architect, 2008).*

The table below shows evaluation results of experiments through different age groups. The results show that cutting the panels does not have the potential to engage different age groups because it requires cutting skills and using different cutting equipment that might be non-applicable for different age groups such as old people and children.

However, this research delivers pre-fabricated emergency shelters to survivors and emergency NGOs would be responsible to assemble and deliver prefabricated emergency shelters to post-earthquake scenarios. In terms of restriction, it should be mentioned that adults need instruction to work with cutting equipment for prototyping and assembling but school children even with instruction are not permitted to cut with knives for prototyping.

	Cutting	**Erection**	**Interest**	**Restrictions**	**Problems**
5-10 years old kids	Un-Successful	Successful	High	Applies (Health and safety)	Unexpected behaviors
17-25 years old University students	With a short induction Successful	Successful	High	N/A	N/A
Adults in different ages (out of university)	With a short induction Successful	Successful	High	N/A	Health and safety
Results	Prefabricating emergency shelters	Self-erection emergency shelter	People are interested in sheltering	The research applies for all groups	

Table 13: *Experimenting the potential of public engagement in different age groups (By author)*

[78] The JA architect journal: The Japan Architects Association.

6.8.1 Recycled Cardboards

Depending on the structural type of emergency shelters, there are many efficient material options from the paper industry, which can be applied. One of the most sustainable and low-cost options in the paper industry is recycled cardboard. Recycled cardboards can be manufactured at a low cost, environmental-friendly, toxicity free and degradable.

This section discusses about potential of recycled cardboards as a main material option for emergency sheltering. Literature Review considered recycled cardboards in three scales including world scale, national scale in Iran and province scale. Statistics from the section Recycled Cardboard in the Literature Review (x ref) show that high percentage of world recycling belongs to Europe. In addition, as Charts 6.2 and 6.3 show the percentage of paper recycling increases in the world gradually and it causes more sustainability and potential to be applied as one of the main material options for this research. Statistics in Iran and Kerman province are same and increasing yearly.(x ref)

Recycled cardboard can be implemented as a surface deployable structure because it is available in different technical features, sizes of sheets. For example, corrugated cardboards are types of cardboard, which consist of half-rolled paper in the centre of it. Normal cardboard in comparison with other material options are very low-cost and in some cases can be found free in recycling stations.

However, normal cardboard could be a risky material option for emergency sheltering in different climates because cardboard under rain absorbs water and it causes deformation of panels, leakage and collapsing shelters. Therefore, normal cardboard cannot be an efficient material option for long-term use in rainy and snowy climates.

This research in previous chapter considered different types of new emergency shelters such as Global Village shelter which is made of cardboards (x ref). Many advantages and disadvantages are mentioned for that shelter. This research applied advantages of that shelter and similar researches including cardboards as a material option. There are special types of waterproof and fire resistant cardboard for emergency sheltering. Cardboard for emergency sheltering should have specific technical information which are expanded in this chapter (x ref). Prototyping through thin cardboard causes instability of prototypes and collapsing. On the other hand, thick cardboard is difficult to fold, cut, pack and transport. The ideal technical information of normal cardboard is gained from the Shigeru Ban’s experience in the building industry including emergency sheltering (McQuaid, 2003). In his book one chapter concerns experiments about different types of cardboard and paper tubes which this research applied for prototyping; technical details are provided in the portfolio for each prototype. In addition, as the figure 6.16 shows Shigeru Ban designed emergency shelters by paper in Rwanda.

> "Ban's design came after several months of evaluating several potential materials for the shelter's frame, including bamboo, aluminium, plastic, and paper tube." (McQuaid, 2003:30).

Figure 6.15: *Stack of recycled cardboard for prototyping (By author)*

Figure 6.16: *A paper tube tent designed by Shigeru Ban* (McQuaid, 2003).

The following discusses the potential and possibilities of cardboard in emergency sheltering in Bam. However, this material option in different places has potential to be applied. For instance, chart 6.2 provides statistics of paper recycling in Europe and next part focuses firstly Iran, and Kerman province.

As expanded in the chart in the Literature Review the percentage of paper recycling in Europe is increasing and statistics of paper consumption is decreasing.

The chart below shows the statistics of paper recycling and paper consumption. Additionally, the percentage of paper recycling around the world has increased from 2% in 1991 to 6% in 2012.[79] This percentage shows the potential of this material option for application in emergency sheltering on a global scale.

[79] European Recovered Paper Council (ERPC) Website, Accessed 28/09/2013

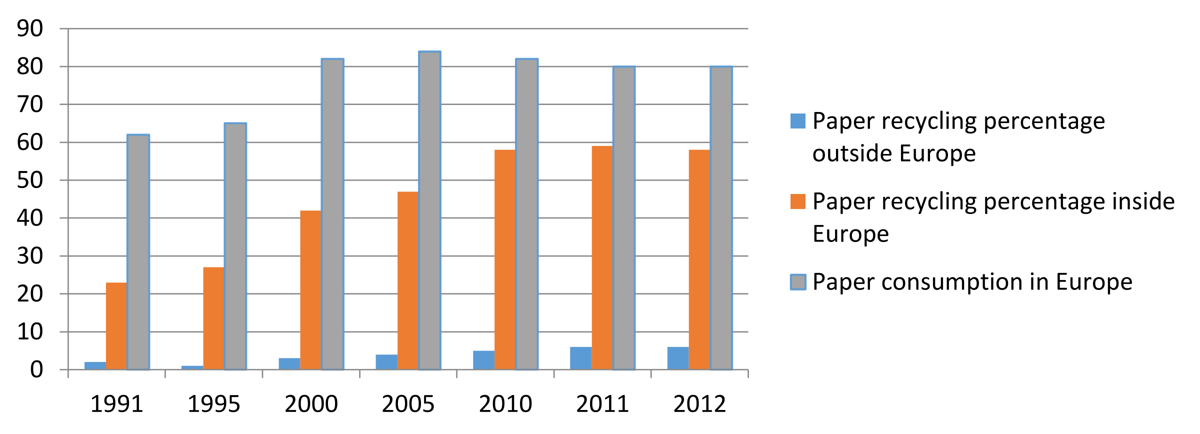
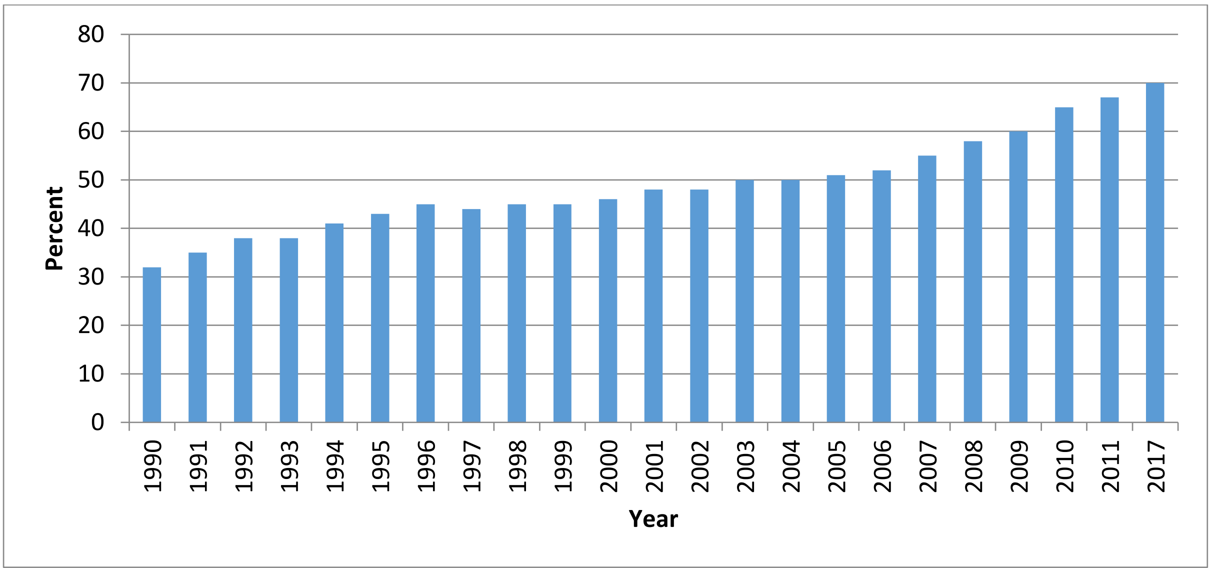


Chart 6.2: *Paper Recycling in European Union (The numbers are in Million tons)*
(Ref: European Recovered Paper Council (ERPC) Website, Accessed 28/09/2013)



Percentage of paper recycling in the world scale,
(Ref:https://sites.psu.edu/congxuncibblog/2014/03/20/paper-recycling)

Regarding the potential of the paper industry for emergency sheltering in Iran, section 1.8 in Literature Review provided percentages and It compares Iran with other Asian countries in terms of paper recycling. As the section 1.8.6 in the Literature Review explains percentage of paper recycling in Iran for 2003 when Bam earthquake happened was 11%, 2013 this number increased to 18% and nowadays this percent is 20%. (search ref)(x ref)

Bam earthquake happened in 2003 while paper recycling in the city of Kerman was 3.525 tonnes per day. There is no official percentage about waste paper collection for recycling in Bam but statistics show that there is no paper recycling factory in Bam and the city of Kerman has only one factory that was founded in 1993. This factory, in 2003, was recycling more than 3.5 ton a day for producing different types of recycled paper products including corrugated cardboard with different thicknesses. Nowadays, in 2017, they recycle 12 tonnes of paper every day, which has the potential to be implemented in emergency sheltering.[80]

The output of this factory in 2003 was 3525 kilo-grams of recycled paper, which can be a huge amount of waste paper with potential to input material for prototyping and manufacturing emergency shelters. For instance, different cardboard prototypes of this research are in different weight between 5-kilo-grams to 32 kilo-grams. Through 3525 kilo-gram of recycled paper a maximum of 110 emergency shelters in surface deployable structure could be manufactured per day in 2003. In addition, these shelters can be manufactured through fire/water resistant cardboards as well. Panel sizes and dimension plans are provided in the portfolio for each prototype.

Figure 6.17: *Thirty-two kilogram prototypes that was made by 120 cardboard panels (By author)*

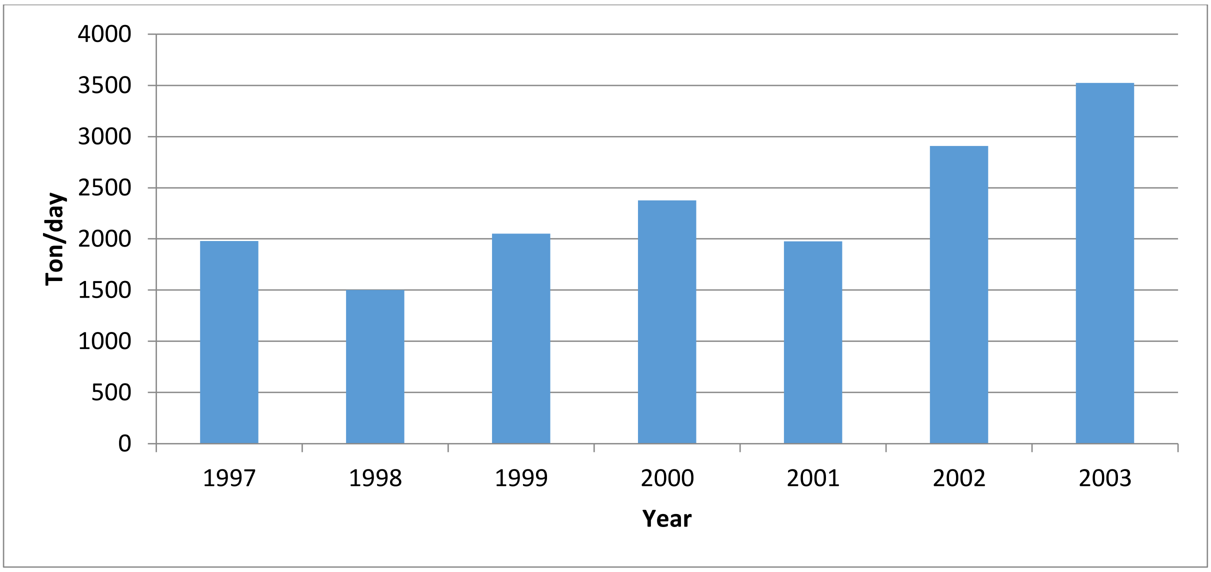


Chart 6.3: *Paper recycling in Kerman 6 years before earthquake (Ref: Iranian Association of Paper and Cellulose Products, Access date: 01/06/2015)*

80 http://kermanpaper.com

Therefore, with consideration to all of the possibilities in Bam including increasing percentage of paper recycling and industrial neighbourhood with paper recycling factory this research considers cardboard as main material option for emergency sheltering because it is a sustainable, environmental-friendly and degradable material option. The chapter considers consuming paper products as one of the main material options for surface deployable structures. Between paper product priority is recycled cardboard which is low cost in Bam. As the panel dimensions of different prototypes show (See volume B prototype dimension sheets), cardboard should be cut in different physical shapes and thicknesses.

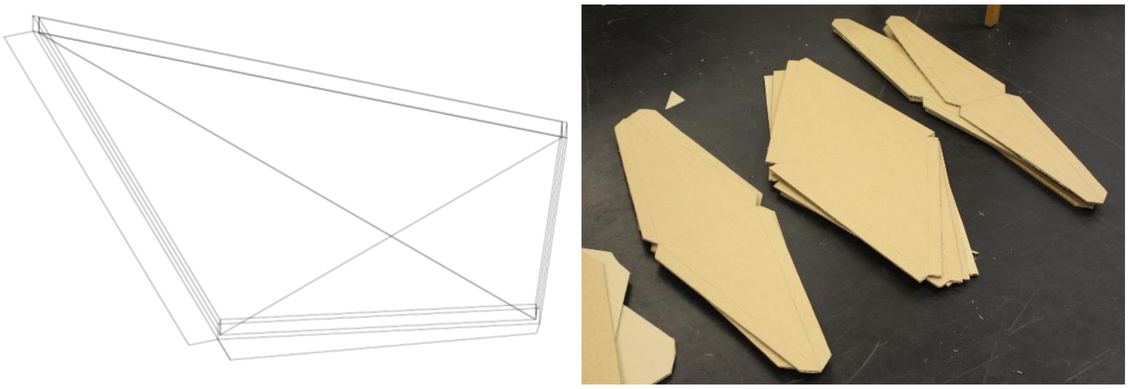


Figure 6.18*: Cutting panels in different physical shapes and dimensions (By author)*

Prices of different types of cardboard in the Kerman recycling factory is per kilograms. For instance, 100kg double layers corrugated cardboard with 7mm thickness, which can be manufactured in different sizes is 2,340,000 Rials (78 USD).

6.8.2 Waterproof Cardboard

Generally waterproof cardboard is used for outdoor uses and wet environments. Waterproof cardboard is durable and tear- resistant, which makes it an ideal material option for emergency sheltering in this research.

As previously stated an interview conducted with Dr Philip Tougher on February 2013 (x ref) water resistant cardboard can be manufactured in factories through low or high tech methods. In addition, there are two low tech methods to make a normal cardboard waterproof. The first method is spraying polymers on cardboard, that has a simple instruction. The first method is called “Nanoparticle Spay”. This technology sprays a polymer, called “monomer”. This covers paper fibres by this polymer. Second method is sticking laminated layer on top of cardboard which has a simple instruction. Therefore, tears cannot separate fibres, they stick together, so that the shape and texture of the cardboard remain the same (Shin, 2012).

Waterproof cardboard is an ideal material option for emergency sheltering in this research because local cardboard factory manufactures normal cardboards and waterproof cardboard which is required during rainy seasons in the Bam.

Chart below shows Bam in average has 22 days rain in December. Therefore, with Bam earthquake which happened in 26th of December, prototyping water resistant emergency shelters is necessary. However, as the chart below shows during June, July, August, September and October normal corrugated for short term temporary sheltering would be efficient. Water resistant cardboard would be one of the main material options for emergency sheltering because of its advantages the author applied corrugated waterproof cardboard in optimum choice. Waterproof cardboard meets all the items in research material selection diagram. It is lightweight, water resistant, degradable and eco-friendliness.

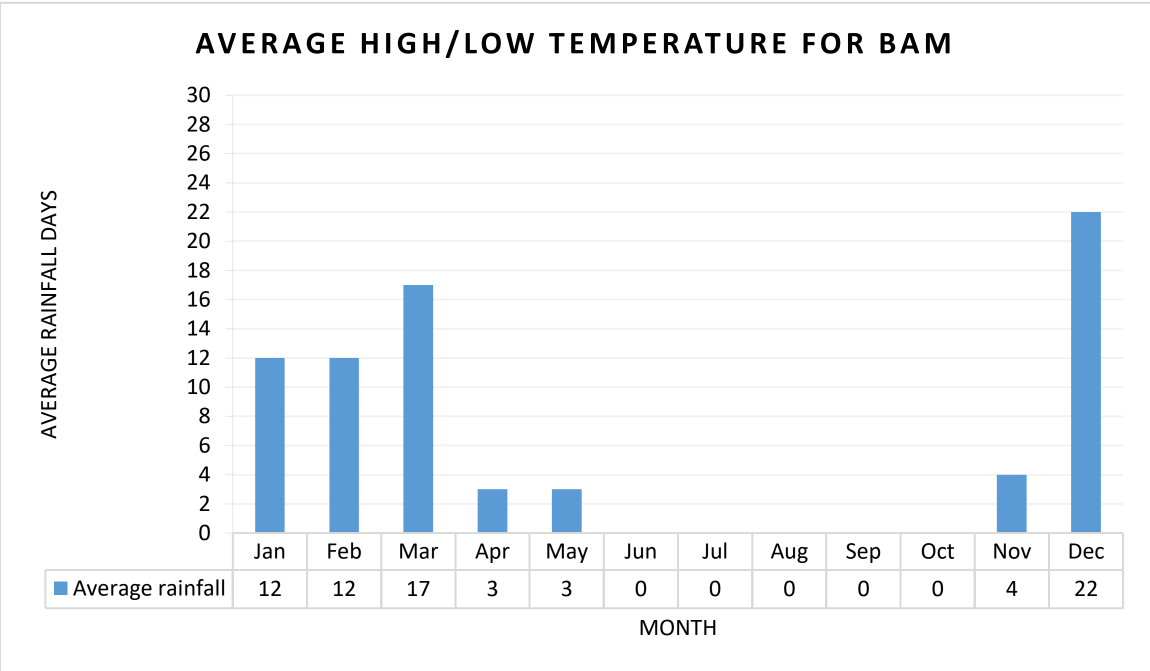


Chart 6.2: *Average rainfall for Bam over a year 2000-2012*
(Ref:www.worldweatheronline.com)

With the development of technology, the cost of waterproof cardboards is decreasing and quality is improving with less environmental toxicity. This research applied this lightweight, waterproof and environmental-friendly material option for emergency sheltering. Normal cardboards, recycled cardboards and water resistant cardboard from Kerman recycling paper factory have the potential to be implemented for emergency sheltering. this research prototyped optimum choice of portfolio with recycled cardboard in scale 1:1 which after testing was stable and efficient. Portfolio documented process of prototyping in actual scale and testing. (x ref)

6.8.3 Fire resistant Cardboard

As previously stated, with the development of technology, paper technologists have innovated fire-resistant cardboard through different methods. Cardboard factories can change the surface of the cardboard in a technological process called dehydration and in some cases, they cover it with special materials called "Fire retard coating" creating fire resistant cardboard (Hugues et al., 2004).

There is no factory in the Kerman province to manufacture fire resistant cardboards. Therefore, most of the shops in Bam should order it from the Tehran paper market, which costs more. However, the fire retard coating spray is available separately. Fire resistant emergency shelter improves health and safety in emergency sheltering which never applied before as there are 1 reported burnt tents in the Bam post-earthquake scenario. Therefore, it is important to apply fire resistant emergency shelters specially in field kitchens and flied hospitals for short and mid-term temporary sheltering.

Fire retard coating can be applied for wood and paper too. The implementation of fire resistant cardboard in emergency sheltering as a material option covers another item from research material selection diagram (Diagram 6.1).

6.8.4 Paper Tubes

This product of the paper industry is considered to be applied as a main material option in telescopic deployable structures (x ref). Same as other paper product, It is sustainable, lightweight, environmental-friendly, low cost, degradable. Paper tubes can be applied in umbrella deployable structures too.

With Shigeru Ban's example for implementing the paper and specially paper tube in the building industry, including emergency sheltering (x ref), it shows that it has the potential to be applied as a material option for prototyping in this research. This material option was designed to be applied in geodesic dome to increase to height of the shelter same a figure below.

In recent years, the technology of papermaking has been improved. As a result, there are different types of papers and paper tube for rainy and snowy climatic conditions. For example, as expanded in the Literature Review paper tube section, Shigeru Ban applied water resistant paper tubes for transitional sheltering in Turkey (x ref) and paper tubes were used as exterior walls. Shigeru Ban's lab is manufacturing different types of paper tubes to be utilized in building industry therefore this research planned to apply the same type of paper and paper tube in erectable/foldable emergency shelter. For instance, this research planned to apply paper tubes, which have a 2-inch diameter and 0.16-inch thickness. Paper-tubes are an ideal material option for telescopic deployable structures because of its physical shape. However, after prototyping optimum choice, strut deployable structures utilising scissor action was not selected as optimum choice as research output. Telescopic deployable structure is not applicable in research output which is surface deployable structure.

Kerman recycling factory does not produce paper tubes, therefore in the case of Bam paper tubes should be manufactured in other cities then it can be delivered to Bam.

6.9 Material Options from Chemical material industry:

This group of material options for emergency sheltering consists of different chemical products of oil, gas and minerals. The research identified lightweight materials for emergency sheltering. The material options, which have the potential to be implemented in emergency sheltering are below. Most of these materials are available in the market in different sizes and thicknesses with different qualities and prices. Considered material options for emergency sheltering which are mentioned below are available in Bam.

Chemical/Technological Material options with potential of implementation in emergency sheltering
- Plastic
- Plastic Cement board

Diagram 6.13: *Chemical/low-tech Material options (By author).*

Plastic: Generally, plastic is the name of the polymers that come from the petro-chemical industry. The most common type of plastic in our daily life is Polyethylene. There are many types of plastics in the world. "Plastics mostly come from petrochemical industry but many are partially natural" (Engelsmann et al., 2010).

This material because of the variety in types has different technical properties. Some types of plastics can be environmental-friendly and degradable, which is the most efficient type of plastic for this research. This material option is available in different sizes, colours and technical information such as different melting points, density and different prices in the Bam market.

Chemical properties of polyethylene are not related to this research but because of availability and experience of using in the Bam post-earthquake scenario, this chapter concerned it to apply as a material option. However, in terms of physical properties it is important to mention that polyethylene has a melting point between 105 to 115 centigrade for normal polyethylene which used commercially (de Pablo et al., 1992). This material option is suitable for laser cutter.

This research applies 3.5mm polyethylene, the same as the Ha-ori deployable umbrella that was expanded on previously (x ref). This material option meets all of the items of material selection (Diagram 6.1) for emergency sheltering. Plastic sheets have the potential to be cut by a laser cutter plotter. This material can be used as one of the main material options for emergency sheltering.

It is important to remind that the research priority is to apply sustainable methods of material selection including conservation, repositioning and replacing of available materials in the Bam post-earthquake scenario.

There are three factories in the city of Kerman, which produce different sizes, thicknesses and colours of plastic sheets for different purposes including the building industry. The price of a sheet of 3.5 mm polyethylene in Bam is 17,500 Rials (0.50 USD) per square metres.

Plastic Cement board: Plastic cement board is another material option which this chapter concerned to apply as secondary material option to upgrade shelters to fire resistant shelter. Plastic cement board consists of a sheet of plastic in the centre and a layer of cement covering the outer layer. This material in emergency sheltering has more advantages in comparison with plastic products because the outer cement layer makes it fire resistant. Secondly layers of plastics and cement would be insulation layers for heat and noise. The cement in the structure of this material option can increase the weight of the board and it might not be available in every location.

6.10 Material options for insulating in Bam

There are different material options in the building industry in Iran, which are popular for housing. Some of these material options are readily available in Bam and low cost. Therefore, survivors can apply this material options for upgrading their emergency shelters easily. Some of these natural materials from the building industry in Iran are as expanded upon below.

Sheep’s wool: As expanded in Chapter Three, section 3.2.4 (x ref) livestock is the second most important industry in Bam and some material options such as sheep’s wool are low cost and available. This material through history has been implemented as an insulation material. In contemporary architecture around the world including Bam, this material is used for insulation in the building industry.

The advantage of this material option is the availability of sheep’s wool in Bam and other locations with the livestock industry. The other advantages are familiarity of this material between rural and urban residents and it is low cost, environmental-friendly degradable, toxicity free. Therefore, it has the potential to be implemented as a secondary material option for the insulation of designed emergency shelters for long-term sustainability. Detail of insulating emergency shelter is provided in portfolio page (x ref).

This material option has the potential to be implemented for cold climate emergency sheltering. The price of sheep wool for those survivors who have to buy it for insulating their shelters, would be 24,800 Rials (0.80 USD) per square metre with 5cm thickness. Sheep wool for livestock owners in Bam could be free.

Mineral wool: Mineral wool is a common material option in building industry in national scale including Bam. Mineral wool is “A synthetic fibre manufactured from glass, stone and slag smelt.” (Hugues et al., 2004:54). This material is lightweight with a flexible physical shape which is an efficient insulation material. It has the potential to be implemented inside the emergency shelters as an insulation layer. This material option is low cost and more popular for insulating partitions. This is an efficient readily available material to apply in emergency sheltering in Bam. It can be manufactured from recycled materials and in the form of roll and panels in different thicknesses and sizes, which is useful for emergency sheltering. Finally, it is an appropriate material option for cold climate emergency sheltering because its insulation density is close to the material option called “Rockwool” which was applied in cold climate emergency shelter designed in the University of Cambridge (See section 1.6.3) x ref). Price of 50mm thick mineral wool with double side foil in Bam is 15,800 Rials (x ref USD) per square metre, which is very low cost in comparison with sheep’s wool.

6.11 Conclusion

Material Design Chapter through consideration of the situations in Bam and similar post-earthquake scenarios develops emergency sheltering in different aspects. This research in volume B as the portfolio applies output of this chapter for prototyping. Below is the summaries of the output for Material Design Chapter

This chapter emphasizes lightweight materials because output of this research would be delivered as prefabricated shelters in a folded position. Therefore, the weight of the shelter plays an important role in the efficiency of emergency shelters in post-earthquake scenarios. Selection of the lightweight materials which are readily available in Bam are considered. Out of these materials some of them had potential to be applied in emergency sheltering and some didn’t have potential.

This research introduced a diagram for sustainable material selection for emergency sheltering. According to the Diagram 6.1 materials for prototyping emergency shelter should be lightweight, environmental-friendly, low-cost, water-resistant, fire-resistant, toxicity free, durable. The chapter introduces concepts of sustainable materials for emergency sheltering and the relation between different scales of the prototypes and materials for prototyping (x ref). It concerns about the efficiency of sustainable material during emergency sheltering and the degradability and toxicity after disposal in short term and long term.

Furthermore, material selection is linked to cultural issues and this chapter identified familiar and common materials for short term emergency sheltering and characteristic material options for long term sheltering. This chapter divides material options into short term emergency sheltering and long-term emergency sheltering (x ref). As expanded in Chapter One, with the increasing length of settlement cultural issues gets more important, this research with creative design in portfolio provided flexibility for survivors and emergency NGOs to upgrade emergency shelters for longer term. The output of shelter for long term settlement would be similar to local ancient traditional shelter which is made of palm leaves in dome shape. (X ref to “Kapar”). Earthquake survivors are able to upgrade their shelter through the installation of palm leaves with their local skills. This is expanded on in portfolio (x ref).

This research prioritized materiality in emergency sheltering for the first time. Primary materials with global approach should be familiar and common such as wood for strut making or cardboard for panel making. In the other hand, this chapter introduces secondary materials which are local and characteristic such as palm leaves and sheep wool in Bam. The potential of manufacturing all material options in Bam were considered and expanded in this chapter. More importantly, this research considered sustainable methods of material selection including conservation, replacement, repositioning of building waste materials from collapsed houses as survivors collected these for the reconstruction of their permanent shelters.

The availability and familiarity of primary materials of this research on a global scale, provides different possibilities for emergency services such as responding quickly to a post-earthquake scenario with lightweight and self-erection emergency shelters. Emergency services have the possibility to be prototyped and manufactured through lightweight, environmental-friendly, degradable material options, which are lower cost, lightweight, waterproof, fire resistant from different industries such as the paper industry.

In the next step, emergency services and survivors through time are able to equip and upgrade their emergency shelters with secondary materials options, which are locally sustainable. Therefore, they will be able to live for a longer term in sustainable emergency shelters.

Primary and secondary material options were considered through their physical shape and different engineering methods to make lightweight emergency shelters. As a result, this research applies deployable structures, which are made by lightweight materials.

In addition, different primary and secondary material options, of this research are selected through local industries such as the wood industry with different types of wood, the paper industry with recycled cardboard and chemical materials with recycled plastic board. Moreover, different available composites, which are common and available for the building industry in Bam, are suggested for prototyping. Suggested primary material options were: solid wood, board, plywood, recycled cardboard, waterproof cardboard, fire resistant cardboard, paper tubes and plastic which were locally available to be applied as primary material options in Bam. In addition, Palm leaf, plywood, Oriented Strand Board (OSB), fibre boards, fibre-reinforced board, fibre cement board, gypsum fibreboard and plastic cement board are the material options, which have the potential to be applied as secondary material options. These material options also could be collected from collapsed houses in the Bam post-earthquake scenario as a source of material options. Furthermore, sheep's wool and mineral wool are the common insulation material options in Bam, which can be applied as an available material for insulating emergency shelters.

Finally, this research, with all of the material options as outputs of this chapter and material selection diagram as an important diagram for material selection for emergency sheltering, started prototyping. Prototyping has been done to evaluate potential of each primary and secondary material options for each type of emergency shelters. Architectural and technical information of the proposed prototypes are expanded upon in portfolio.

Chapter 7: Conclusion

7.1 Summary of findings and evaluation of the research questions

Introduction

This research based on UN provision started identification of problems in temporary sheltering with reference to the experience of the Bam earthquake. The main question of this research is derived from the current earthquake response cycle that emergency NGOs and survivors are struggling with sheltering and providing appropriate and efficient emergency shelters.

According to the survivor's situation in Bam, this research analysed problems of the temporary sheltering process in post-earthquake scenarios. Different emergency NGOs responded to survivor's immediate needs in Bam post-earthquake scenario nationally and internationally. This research focused on typology of immediate needs and required spaces to identify immediate architectural needs.

Political and economic conditions were the main issues that affected the quality and length of temporary sheltering in Bam. However, other issues such as geographic, historical and climatic conditions were significant too. Through considering United Nations responses, the disaster response cycle consists of different stages. This cycle covers architectural needs for all affected people including survivors and NGOs. Identified problems in existing temporary shelters, affects quality of lives.

Generally, architectural responses start with emergency sheltering, continues with transitional sheltering and finally ends with permanent sheltering. The stages of the disaster response cycle in developing, developed and poor countries are the same but the length of stages could be different. The main question of this research is derived from temporary sheltering in the current earthquake response cycle how we should develop sustainable temporary structures and infrastructures to support immediate or longer-term needs in post-earthquake scenarios.

This practical research responded to this research question by designing sustainable self-construction emergency shelters. It happened through accurate investigation in the Bam post-earthquake scenario and interviews with survivors and NGOs to identify depth of gaps in Bam. This research discussed through Disaster Response Cycle, Structural Design and Material Design to support practical part of the research as output.

The structure of this thesis consists of seven chapter including; Chapter One identified the gaps in emergency sheltering. Chapter Two structures this practical research and research methodology. Chapter Three focuses on Bam to evaluate depth of identified gaps with questioning and statistics. Chapter four responded to first research question by daily basis earthquake response. Finally, Chapters Five and Six addressed the second research question.

Chapter One as a Literature Review supports discussions in other chapters. It expands all issues related to sustainable development in sheltering and the importance of sustainable development in different industries and lack of sustainable design in existing emergency shelters. Earthquake studies with two approaches including earthquake as natural disaster and earthquake as natural event are expanded. Output of these two approaches identified activities before/after earthquakes and technologies which can be applied such as GIS and GPS. Last section of Chapter One provides general information about Bam, typologies in building industry in Bam and available materials. Chapter One identified different lessons learnt from previous earthquakes which some of them directly and some indirectly affects on temporary sheltering. Literature Review identified principles and methods of sheltering in two scales as below.

Literature Review	
World scale	Sustainable development in material and sheltering
	Earthquake studies
	Principle of emergency sheltering
	Requirements for temporary sheltering
	Camp management
Bam Scale	Strategies for temporary sheltering in Bam
	Temporary sheltering approaches for the Bam earthquake
	Planning patterns and applied patterns in Bam
	Process of site selection for temporary sheltering

Literature Review discussed advantages and disadvantages surrounding temporary sheltering in post-earthquake scenario to identify gaps. These gaps are upon below which were identified in Literature Review:

- Lack of self-construction emergency shelter in post-earthquake scenarios as in Bam earthquake, 20% of survivors had to wait for trained volunteers to erect their tents. This percentage in Baravat and villages around Bam was higher because emergency NGOs had difficulty to access. In addition, because of complexity of situation and change of temporary sheltering strategy, NGOs started training Bam survivors in post-earthquake scenario to erect their tents by themselves rather than sending trained volunteers to survivor’ land to erect emergency shelters.

- Delivered tents in Bam post-earthquake scenario and existing equipment for emergency sheltering are designed for a short-term settlement while in Bam it was used for mid/long-term sheltering. Survivors had to live from December as coldest month till June and July as hottest time of the year. It took three to four days to provide electric heaters and power in Bam post-earthquake scenario. In some cases, use of fossil fuel in first four days caused fire in tents.

- Emergency NGOs had to wait for highly trained volunteers and cranes to erect their large-scale tents. Therefore, they erected different numbers of small size tents to provide enough space for their services.

- Families in Bam are generally are big and consist of many people that live close together in neighbourhood in same districts. However, they had to live in groups of four in the Bam post-earthquake scenario before and after changing temporary sheltering strategy. For instance, a couple with four or five children had to live in two separate tents and in some cases in different locations in camps which is completely different as their lifestyle.

- Survivors and emergency NGOs applied fossils fuels, electric heater, palm leaves, electric fans, and plastic sheets for to cope with cold and hot climate conditions. Sustainability in emergency sheltering is another issue for this research, is developed by creative design.

- Survivors who reused their tents after moving to transitional shelters and permanent shelters had to upgrade with secondary materials or change whole tarpaulin or canvas.

Literature Review support discussions in chapters Four, Five and Six to address those identified gaps in current emergency sheltering. For this reason, Chapters Three and Four are designed to provide answers to the subsidiary research question what are the immediate architectural needs of people in the Bam post-earthquake scenario.

The Bam earthquake had effective and important lessons for this research, for instance training plans demonstrated that emergency NGOs need to train volunteers and people for different actions including erection of tents to improve the level of preparedness for earthquakes and minimise the level of damages. Level of damages in the Bam earthquake was unexpectedly high and it made disaster response cycle complicated.

Changing strategy of temporary sheltering from camps to survivor's land was another issue which was the sign of inefficient post-earthquake management in Bam. Therefore, training survivors for emergency shelter erection was important to erect their shelters in their own property. This strategy changing helped survivors to live in Bam with same life-style.

This research started considering the Bam earthquake response cycle through two views to focus on depth of immediate architectural responses. Firstly, survivors view, secondly NGOs view. The view from the survivor's side starts from beginning of the scenario, when an earthquake occurred and it consists of six steps while disaster response cycle from emergency NGOs consists of five steps. Below is summery of services for both views.

	Survivors view
1	Rescuing threatened people
2	Emergency rescue of trapped people
3	Medical response to injured people
4	Transferring those injured people to field hospitals or other first aid points in post-earthquake scenarios.
5	Emergency sheltering for survivors and providing food, water or other medical aid.

	Emergency NGOs view
1	Relief
2	Rehabilitation
3	Landscape recovery
4	Preparedness
5	Mitigation
6	Reconstruction

This chapter expanded the experience of the author as a volunteer who engaged and observed all of the emergency responses nationally and internationally closely, and observed that NGOs had limitation in responding because of the ancient Bam citadel. The author's experience of how national and international emergency NGOs coped with earthquake site conditions to deliver emergency shelters and train volunteers to erection emergency shelters in the Bam post-earthquake scenario.

In addition, it was stated that with existing knowledge about earthquakes, geophysicists can identify areas with risk of earthquake that mostly are based on the edges of tectonic plates (Figure 1.2). Identification of these areas has many advantages such as providing possibilities to select local materials for more sustainability (Table 15). This research through this method identified appropriate and sustainable local materials in building industry in Persian Gulf countries. Sustainability is another issue in emergency sheltering which this research responded to this issue to develop emergency sheltering in Bam.

This Chapter provided data related to UN guides for emergency sheltering (sections 1.6.6 – 1.7) which were applied in designing outputs for this research. For instance, minimum tent size should be 12 square metres with separate toilet and shower (See section 4.6.4 and diagram 1.5).

Chapter Two applied research methodology cycle (Diagram 2.1) that borrowed from a variety of disciplines to help this research. Methodology diagram illustrates that research methodology consists of four key steps, which structured different activities of this research through different qualitative and quantitative research methods for Volume A and B. Different types of interviews, workshops and seminars were planned for this research.

In addition, theoretical framework for the research methodology was considered. It helped this research to focus on post-earthquake scenarios and research methods, which other researchers have done. For instance, research methods of Dr Fallahi in terms of technical issues in post-earthquake reconstruction or Johnson's research methods in disaster response strategies or Fayazi's research methods about social issues were considered. According to the area of their works and applied research methods, different questions related to temporary sheltering were designed for this research. These questions shaped research questionnaire for fieldworks in the Bam. These questions targeted specific groups of affected people in the Bam post-earthquake scenario to identify their architectural needs in different stages of post-earthquake scenario. Some of these questions asked about preparation of temporary shelters in post-earthquake scenario, some asked about security, health and safety, some about social and lifestyle in the Bam post-earthquake scenario. (x ref)

The research methodology designed different activities for action such as conducting workshops for digital modelling, small scale modelling and actual modelling. All activities follows specifics purpose, which were expanded in Chapter Two.

In the third step of research methodology as Feedback, this research tested outputs with groups of non-specialist and people with architectural skills in Beheshti School of Architecture and Manchester School of Architecture to evaluate their efficiencies and feedback from volunteers. Secondly, this research presented outputs to group of experts such as groups of students in MA Disaster Reconstruction Management through a seminar. After this seminar the author received valuable feedbacks for further development. Finally, Dr Fallahi and his colleagues as a members of Iranian Red Crescent research committee commented about theoretical and practical part of the research outputs which caused changes.

Chapters Bam fieldwork as Chapter Three and Disaster Response cycle as Chapter Four are designed to address first research question which is; what are the immediate architectural needs of people in post-earthquake scenario.

Chapter Three discussed and evaluated the results of fieldworks in Iran surrounding temporary sheltering. It evaluated situation of Bam before earthquake and compared situation after earthquake. It evaluated potential of identified material options in Bam from Literature Review. It also questions Bam survivors through designed questionnaire in Chapter 2 (x ref). Chapter Three focused in depth on identified gaps in Literature Review with providing different statistics and charts related to temporary sheltering in Bam. Below is summary of fieldwork:

Bam is a garden city and gardens improves climatic conditions in Bam for leaving. People of Bam are dependent to their palm gardens in Bam and Baravat. In fact, palm tree is part of their daily life.

- Location of survivors for temporary sheltering after changing strategy from camps to survivor's land showed that 60% of survivors preferred to live in their private lands rather than camps. Therefore, it was important to send someone to their private gardens to erect their tents. Self-erection emergency shelter and mobility were important factors for designed prototypes because it took more time and cost more for emergency NGOs to erect tents in camps then transfer them from camps to their private lands. NGOs had to send their trained volunteer to survivor's land for erection of their shelters.

- Number of survivors in each tents showed that 70% of survivors were group of four in a tent. 20% of them were living more than 4 people in a tent which are designed for 4 people. As expanded, families in Bam in average consists of 6-8 people. Therefore, possibility of extension in prototypes of this research was important to improve the quality of life.

- Reusing emergency shelter for different purposes was important as 85% of survivors reused their tents. Therefore, durability and designing tents for long-term was important for this research to develop emergency shelters.

- The process of emergency sheltering was too slow because of complexity of situation and inefficient post-earthquake management. Statistics show that 10% of survivors engaged with emergency sheltering and rest of them had to wait for trained volunteers.

- For 50% of survivors was important to live with or close to their family, friends and relatives. In the other words 50% of survivors were dependent.

- 55% of survivors in Bam earthquake had experience of using palm leaf or other material is the post-earthquake scenario to upgrade their tents for cold and hot climates. Few days after Bam earthquake survivors used fossil fuel for heating which in some cases caused fire. This research responded to this issue with application of secondary fire-resistant material options as well as palm leaves installation details.

Chapter Three through considering survivors/NGOs situations on daily basis and collating direct quotes from politicians who managed Bam earthquake identified the survivor's immediate needs and times to respond architecturally. For instance, Table 4.3 lists required spaces in Bam post-earthquake scenario, which includes central command tent, telecommunication unit tent, field clinic, field hospital, survivor's tents, field kitchen, field stores, nursery and elderly houses and security units. Required spaces for different purposes in post-earthquake scenario is different. For instance, in Bam required space for 1 field hospital was more than nursery. The field hospital in Amir Camp consisted of 3 huge scale tent while nursery was a big size tent.

Chapter Four analyses the effects of strategy changing of government from camps to survivor's land in terms of temporary sheltering. Moving temporary shelters to private lands made length of settlement in temporary shelters longer because emergency shelters in gardens became out of control of emergency NGOs while in camps could control. Records show that emergency sheltering in Bam took seven months from December to July. This research responded to cold and hot climate with designing short term and long-term emergency shelters for more sustainability. Short and long-term emergency shelter is designed through structural design and material design.

Finally, these statistics show 14 years after Bam earthquake, 50% of survivors ranked very bad as level of satisfaction while they had better experience in transitional sheltering.

The Chapters Five and Six discussed the main research question, how should we develop sustainable temporary structures and infrastructures to support immediate or long-term needs in post-earthquake scenarios?

Chapter Five responds to identified gaps in Literature Review through identification of structural types, which have potential to be erectable and foldable. Secondly, this chapter concerns modular design for more flexibility and multi-purpose design.

Structural Design Chapter started with explaining the differences between complex structural action and basic structural action. It focuses on the different factors of basic structural actions and the role of mathematical calculation in both groups. It helped to identify basic structural groups that have the potential to be implemented in emergency sheltering.

In addition, structural design started application of architectural/engineering factors, which were identified in Literature Review. Therefore, as an implication this chapter designed its own structural design diagram for emergency sheltering. In this diagram the research is concerned about scale, energy saving, cost and material efficiency in emergency sheltering. Furthermore, iconic deployable structures, which are familiar such as geodesic dome or pantograph, helped this research to simplify erection of structures.

> “Most people are familiar with the hinged mechanisms or pantographs” (Chilton, 1999:140).

One of most important outputs of this chapter is shaping the deployable structure diagram with architectural focus for emergency sheltering. This diagram is the result of identification different types of deployable structures according to their shapes and mechanisms with an engineering focus. These erectable and foldable structures are named with familiar instruments and tools to simplify the erection mechanism such as deployable structure with accordion mechanism or umbrella mechanism.

After investigating deployable structure with engineering focus, research classifies with architectural focus including; surface deployable structures and strut deployable structures. Surface deployable structures are in accordion mechanism, telescopic mechanism and inflatable mechanism while strut deployable structures are in strut deployable structures utilizing scissor action and umbrella mechanism. Different types of contemporary emergency shelters in different structural types were considered to identify advantages and disadvantages of those designs. This research applied advantages and improved disadvantages which caused NGOs developments in emergency sheltering. For instance, Global Village shelter was low-cost, sustainable, lightweight and it could work every location. However, it had some disadvantages too. Disadvantages such as; firstly, it needs tools to erect and assemble. Secondly it is not extendable for families with more family members and not upgradeable for midterm use. These examples were concept of emergency shelter developments to comply UN requirements and identified gaps which was expanded in Chapters One, Two and Three.

In Structural Design Chapter, different deployable structural options were discussed how can be applied as an option for sheltering. Selected deployable structures were prototyped to evaluate its potential in actual scale. For instance, inflatable structures were not selected in Chapter Five because it is not efficient in long term and first few hours after earthquake there is no power, air pump or other equipment for inflating. This chapter responded to identified gaps in Literature Review including waiting for trained volunteers to erect tents or lack of possibility to extend. This chapter provided modular design and provided technical details to extent designed shelters. It caused more flexibility and having multi-purpose shelter. Portfolio documented all types of selected deployable structures in this chapter for prototyping.

Selected structures shaped taxonomy sheet in portfolio. Those selected structures were prototyped through specific process including digital modelling, small scale modelling and actual scale modelling. Finally, all prototypes in selected structures were tested in terms of erection and stability. Some of selected structures were failed after prototyping in actual scale or after testing. Optimum design was selected and documented in volume B.

Material Design as Chapter Six identified readily available material options in Bam for emergency sheltering. All of the possibilities in Bam are considered in this chapter. This chapter responds to the identified gaps in shelter materiality. The sustainable approach in this chapter plays an important role in sustainability of research output. Sustainable lightweight material selection for emergency sheltering in this chapter is designed to support the sustainability of this research.

One important output in this chapter was the diagram of Sustainable Methods for Material Selection in emergency sheltering (Diagram 6.5). It identified possible sustainable methods in Bam including conservation, replacement, repositioning and finally recycling as sustainable methods for material selection in emergency and prioritises those methods, which can be applied in Bam post-earthquake scenario. This output x ref) is the result of implicating sustainable material selection methods in different industries.

Application of degradable and toxicity free materials in comparison with applied petrochemical materials in existing tent is a development. In addition, considering fire resistance material options is a response to health and safety in emergency sheltering as this research proved that some tents were burnt in the Bam post-earthquake scenario because of using fossil fuel in tents for cooking (x ref). Water resistance and low cost are other items that this research considered to develop in material selection.

Strategy of material selection in this research is to divide material options in 2 groups. Primary and secondary material options for short term and long-term sheltering. This strategy simplifies transportation, cases lower cost and increases level of sustainability because selected short-term materials are readily available, familiar and common options by public such as cardboard or wood. Secondary material options are more local to maximise sustainability. For instance, this research considered to apply local wood products from wood industry in Bam, cardboards product from Kerman paper recycling factory, rock wool from local Fajr company and other chemical and, petrochemical complex in Bam. Survivors and emergency services during time have the possibility of upgrading their shelters with secondary material options for more sustainability.

In this chapter, all of possible low-tech and high-tech architectural techniques for lighting, ventilation, transportation have been considered.

Volume B of the research, describes the process of development and integration of research outputs in the form of practice. Volume B translates output of Volume A to physical models which has its own methodology cycle. It is expanded in Portfolio page 2. Volume B documents model making, prototyping, experimenting in wood, metal, foam workshops and digital modelling.

Different ranges of prototypes are proposed in the portfolio as emergency shelters. Those prototypes are the result of outputs in Chapters Five and Six to respond identified gaps in the Earthquake Response Cycle. These outputs as prototypes in the scale of one to one have been evaluated and tested by non-specialists and experts in public places. Accordingly, those tests and evaluations are followed by developments. Finally, optimum choice was selected and Portfolio simulates Amir Camp with research outputs to evaluate possibilities and requirements in the camp.

General conclusion and future works

The beginning of the research was the current problems of survivors and NGOs engaged with emergency sheltering. This research developed sustainable mobile architecture with referencing it to the experience of the Bam earthquake through practical experiments.

Comparing output of this research with conditions during the Bam earthquake shows that those identified problem which earthquake survivors had improved. Statistics in Chapter 3 showed that majority of survivors waited for survivors to erect their emergency shelters. 10% of survivors in Bam erected their own tent and they spent between 1 to 2 hours to erect their tents while output of this research was tested by different volunteers in different age groups. The result of the comparison showed that it was successful self-construction emergency shelter. For erection of optimum choice from folded position survivors in average spent 6 minutes without any instructions. In addition, it has potential to be folded and transferred in other location such as survivor’s land because it is lightweight. Furthermore, statistics showed that 20% of survivors had to live separately with family members and relatives because the capacity of tents were only for 4 people while prototypes of this research are extendable to multi units. Finally, all of survivors and NGOs in the Bam post-earthquake scenario lived in single unit tents from coldest month in a year to hottest month. Those tents are not designed for cold climate while optimum choice of this research has potential to be upgraded for cold climate and hot climate with characteristic local materials. It maximises material sustainability in emergency sheltering.

The research methodology of this study has been developed to understand the importance of sustainability in emergency sheltering within this context and formulating the research to address the current and expected future issues towards sustainable emergency sheltering. Accordingly, the methodology of this research developed for the analysis and involved affected people in post-earthquake scenario. The major aspects of emergency sheltering, that analysis and developments occurred, were firstly, in public engagement, which happened through creative structural design and simplifying shelter erection through familiar forms and structures. Secondly, short term and long-term sustainability in emergency sheltering happened through material design. Thirdly, stability/economic/energy efficiency in emergency sheltering happened through prototyping, analysis and evaluating shelter in primary and secondary materials.

Sustainable Mobile Architecture for Natural Disasters with Reference to the Experience of the Bam Earthquake is one of the first researches that considers the flexibility, durability and sustainability of emergency shelters for those survivors who need to stay long term as well as those who need to stay short-term.

This research at the beginning was an individual research with collaboration of Manchester School of Architecture and Beheshti School of Architecture for prototyping and conducting different workshops and seminars. However, the author after field trip to Iran in March 2015 and presenting the research to a group of experts in Beheshti University joint Disaster and Emergency Management network in Beheshti University for research collaboration. The author from Manchester, one researcher from Australia, one from Germany and three in Beheshti University are collaborating with this research centre in Beheshti University for Iranian Disaster and Emergency Management. The author with his academic knowledge and experience in disaster response cycle is collaborating professionally with this research centre.

This research contributes to knowledge with sustainable Mobile Architecture for Natural Disasters with reference to the experience of the Bam earthquake, which never has concerned before. The output of this research also provides a model for future researches related temporary shelter design for post-earthquake scenarios especially in the case of poor and developing countries that survivors because of weakness of their local authorities or complexity of post-earthquake situation, disaster response cycle is longer and poor quality.

Appendix

Appendix1

Name **Age** **Gender:**

Marital status: **Level of education:**

1- Where were you living before Bam earthquake?

Bam **Baravat and other villages**

2- Where were you living during earthquake?

Camp **Private lands**

3- Where do you live now?

Bam **Baravat and other villages**

4- What types of emergency shelter did you use?

Tent **Other type of emergency shelter**

5- What types of transitional shelter did you use?

Porta cabin **Pre-fab cement units** **other types**

6- How many people were in your emergency shelter?

Less than 2 people **Between 2-4 people** **Between 5-7 people**

7- Did you reuse your emergency shelter?

No yes

8- What was the purpose of reusing?

9- Did you reuse your transitional shelter?

No yes

10-What was the purpose of reusing transitional shelter?

11-Did you engage with emergency sheltering?

12-Did you engage with transitional sheltering?

13-How many hours did you spend for emergency sheltering?

Less than 1 hours **Between 1-2 hours** **More than 2 hours**

14-How long did you live in temporary shelters?

Less than 1 year **Between 1-2 years**

Between 3-4 years **More than 4 years**

15-How many times did you feel unsecure and danger?

N/A **1 time** **3-5 times** **More than 5 times**

16-How much is important to live with familiar people in neighbourhood during temporary sheltering?

N/A **Important** **Very important** **Needs someone**

17-How many people were using toilets during temporary sheltering?

2 or less people **3-5 people**

6-8 people **More than 8 people**

18-How many people were using bath during temporary sheltering?

2 or less people **3-5 people**

6-8 people **More than 8 people**

19-When did you start temporary sheltering?

20-When did you finish temporary sheltering?

21-Do you have experience of using any building material during temporary sheltering?

22-How many time did NGOs inspect per month and could you say how many people and how long were each inspection?

Everyday	**1-4 times per week**
1 time per month	**Every 3 month or less**

23-How far was your emergency shelter from your transitional shelter?

Same location	**Less than 1km**
Between 1-20km	**More than 20km**

How do you rate quality of emergency shelter?

Very bad	
Bad	
Middle	
Good	
Very good	

How do you rate quality of transitional shelter?

Very bad	
Bad	
Middle	
Good	
Very good	

Appendix 2: UDHR, 1948, Universal Declaration of Human Rights, 1948

Article 3: “Adequate shelter and housing are a fundamental human right”

Article 12: “No one shall be subjected to arbitrary interference with his privacy, family, home or correspondence, nor to attacks upon his honour and reputation. Everyone has the right to the protect of the law against such interference or attacks”

Article 17: “Everyone has the right to own property alone as well as association with others. No one shall be arbitrarily deprived of his property”

Article 25: “Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food, clothing, housing and medical care and necessary social services, and the right to security in the event of unemployment, sickness, disability, widowhood, old age or other lack of livelihood in circumstances beyond his control.”

Appendix 3

Interview with Dr Philip Tougher at the University of Manchester (UMIST) Paper technology (Interview has been done in February 2013)

FB: Philip as far as I know there are different types of cardboards that we use in daily life and most of the waste is normal cardboards. Where can I find water resistant cardboards for prototyping in my research?

PT: Generally recycled paper litters are designed for different types of papers including normal paper, normal cardboard, waterproof cardboard, paper tubes city councils or other organizations to minimise number of litters in recycle stations or other pints of the city, predicted only one litter or trolley or box for paper products. Moreover, it is not easy for people to recognize different types of paper. For example, people do not distinguish waterproof cardboard from normal cardboard so they bin it in same litter. Therefore, I recommend you to use normal cardboard for its availability in different locations and you can make it waterproof later.

FB: How can I make it waterproof?

PT: There are different methods to make it waterproof. One method is to stick laminated layers that are available in different rolls on the market with different sizes and different technical information. Secondly, you can buy different types of waterproofing sprays to make paper waterproof. The spray is low cost for example 600ML spray should cost £4. You should spray “Polyurethane chemicals” on normal cardboard or paper to make it waterproof.

FB: That is very easy and efficient. Is there any similar method to make paper and cardboards fire resistant? Can we use it for wooden sheets?

PT: Yes, there are similar methods to make cardboards or papers fire resistant but all of these methods cost more.

Appendix 4

An interview has been conducted with Cristina Rodrigues who is a Portuguese architect and PhD researcher in MIRIAD[81]. Cristina as an experienced architect firstly has experience of working with cork because of her professional practices, secondly, cork is a familiar local material in Portugal, and thirdly, she had an interview with Alvaro Siza Vieira who is a famous Portuguese architect and designer of the Cork pavilion in Expo 2000 in Hannover. Below is a part of interview with Cristina.

FB: Cristina could you tell me about cork in Portugal please?

CR: Cork is a type of wood that does important role in our life in Portugal. In our daily life, we use it for different purposes. For example, our seat in our kitchen in Porto are made by cork, which are lightweight. Even my iPhone case is made by cork that is very lightweight and good protection for my mobile.

FB: You are an architect. Do you use cork as main material in architecture in Portugal?

CR: It depends on designers and architect. Generally, cork is very popular for interior design in Portugal however; there are many architects that use cork as structure in their houses. Structure of traditional houses in Portugal, are completely made by cork and in contemporary architecture, I can refer you to Alvaro Siza Vieira who is the designer of the Cork pavilion. One of the concepts of his design was application of traditional Portuguese material.

FB: I have informed you about my research and emergency sheltering for short and long term periods. As a qualified architect, do you think it is an appropriate material option for emergency sheltering at global scale?

CR: In my opinion it can be an efficient material option because as far as I know it could function in all countries as Portugal exports it all over the world. The only concern could be its price. For example, cork in Portugal is very cheap but here in the UK is very expensive. Different reasons such as taxation and transportations in some countries such as UK is high, where everything is very expensive including cork. For emergency in terms of prototyping and manufacturing emergency shelters using cork, I think it depend on physical shape of the cork. If used as panel, it should be very thick because thin panel is very flexible. If used in strut making, I think it should be cut thick too. Generally, as I see your prototypes, I suggest to apply cork as secondary material option because it is not readily available but it can work in different climatic condition in different countries and its transportation bears low cost because it is lightweight in comparison with other materials.

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